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THE NAVAL AIRCRAFT CRASH ENVIRONMENT: AIRCREW SURVIVABILITY AND AIRCRAFT STRUCTURAL RESPONSE

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A study was conducted of U.S. Navy and Marine Corps flight mishaps occurring during the 10-year period of January 1972 to December 1981. One hundred eighty-four helicopter mishaps and 71 maritime aircraft (fixed-wing aircraft without ejection seats) mishaps were examined. Each flight mishap was reconstructed to determine orientation and velocity of the aircraft during the principal impact. Statistical distributions of impact parameters were tabulated for mishaps determined to be survivable. In addition, occupant injuries in each mishap were examined and a hazard which contributed to the injury was assigned. The cost of injuries associated with each hazard were identified and used as criteria for ranking the severity of the hazards.

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It was found that a significant number of major and fatal injuries occur in helicopter flight mishaps classified as survivable. The hazards which contribute to many of these injuries could be reduced in future helicopter designs through the incorporation of current crashworthiness design criteria (which was not imposed on the fleet examined in this study). A similar analysis of injuries and hazards in maritime aircraft flight mishaps indicates that selective use of crashworthy components would be beneficial; however, adoption of a crashworthiness specification to govern an entire aircraft design does not appear to be justifiable by the injury and cost statistics. New regulations, proposed by the Federal Aviation Administration (FAA) for transport and General Aviation Aircraft may be applicable to the Navy's Maritime Aircraft and provide a sufficient increase in safety.

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FOREWORD

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INTRODUCTION

BACKGROUND

The latest generation of military helicopters, the U.S. Navy's SH-60B Seahawk and the U.S. Army's UH-60A Black Hawk and AH-64A Apache, possess unprecedented levels of crashworthiness. The need for including this capability was based on studies conducted in the early 1970's (References 1 and 2), which detailed the crash environment of existing aircraft and the high percentage of major injuries and fatalities occurring in what were considered to be survivable accidents. The U.S. Navy is continuing to improve the crashworthiness of their existing helicopter fleet through retrofit programs in energy-absorbing seating systems (SH-3D/G/H, CH-53A/D/E, UH-1N, CH-46E), strengthened crewseats (SH-2F), flotation systems (CH-46), and emergency underwater lighting (SH-3). Also, under Marine Corps management, the V-22 Osprey tiltrotor aircraft program has considered the incorporation of crashworthiness from the early design stages.

The inherent assumption in these aircraft development and improvement programs is that any weight and cost penalties associated with crash-tolerant design are outweighed by increased readiness and reduced life cycle cost. The study described in this report was commissioned by the Naval Air Development Center (NADC) to provide an evaluation of the existing level of crashworthiness in Navy and Marine aircraft* with fixed seating systems and to identify areas where the advantages of increased crashworthiness could be utilized to their fullest extent. This report covers aspects of the helicopter and maritime aircraft accident environment.

MAGNITUDE OF THE PROBLEM

A tremendous level of effort is expended by the U.S. Navy to minimize the hazards associated with ejecting from high-performance aircraft. As a consequence, it is now becoming apparent that the greatest potential for reducing serious injuries and fatalities (and associated costs) lies in aircraft with fixed seating systems. Table 1 presents a comparison of the number of persons involved in various types of flight mishaps who are either seriously injured or killed. During the 10-year period from 1970 to 1979, 1,123 persons ejected from Navy and Marine aircraft, resulting in 188 fatalities, or 16.7 percent of the total persons who ejected. No nonfatal injuries were reported in the Naval study. During the same period, 1,103 persons were involved in accidents with fixed seating systems, causing 370 fatalities. An additional 175 occupants received major injuries, resulting in a fatality/major injury rate of 49.4 percent. It was concluded in this study that a significant percentage of these fatalities and major injuries occurred in potentially survivable accidents.

*U.S. Navy and Marine aircraft with fixed seating are analyzed as two groups: rotary-wing aircraft, or helicopters, and fixed-wing aircraft without ejection seats, denoted as "maritime aircraft."

Table 1. Comparison of Fatalities and Major Injuries in Various Classes of Navy and Marine Aircraft for CY 1970-1979 (Reference 3)

	Total Number of Persons Involved	Number of Fatalities	Number of Major Injuries
Ejections	1,123	186	*
Collisions with Ground/Water:			
Ejection-Seat Aircraft	130	108	7
Maritime Aircraft	309	195	37
Helicopters	794	175	138

*Not reported.

AIRCRAFT ACCIDENT ANALYSIS

The intent of this study was to develop a statistical data base describing the Navy and Marine helicopter and maritime aircraft accident environments. Each helicopter and maritime aircraft flight mishap during the 10-year period from January 1972 to December 1981 was reconstructed to determine the impact parameters, which consisted of aircraft orientation and velocity relative to the impact surface. Injuries were also tabulated and, whenever possible, a cause or hazard producing the injury was cited. The accident evaluation was based on data gathered from the following four sources:

1. The flight surgeon's report.
2. A brief narrative and key parameter summary supplied by the Naval Safety Center.
3. A detailed review of the entire aircraft accident report (AAR) contained on microfilm at the Naval Safety Center.
4. Data from Sikorsky on-site investigations (when applicable).

OUTLINE OF REPORT

The report is divided into three parts. The first two address helicopters and maritime aircraft, respectively. Each of these parts is organized into sections representing the major segments of the study, as follows:

Accident Samples - Discusses the composition and characteristics of the helicopter accident sample used in this study.

Impact Parameters - Presents the distribution of impact angle and velocity change in the major impact.

Injury/Hazard Analysis - Presents an analysis of injuries, their causes, and associated costs.

Severity Level Analysis - Relates the accident severity (based on impact velocity) to potential for injury from various hazards.

The final part presents conclusions and recommendations based on analyses conducted in this study.

DEFINITIONS

The following terms are defined according to the intent and usage in this report.

Principal Impact

Principal impact is defined as that portion of the deceleration time history when the majority of the decelerative forces were experienced and the most damage was sustained by the fuselage. The principal impact might have been the initial impact.

Impact Velocity Change

The impact velocity change was defined as the change in the velocity component in the aircraft coordinate system according to the following definition:

$$\Delta V = \sqrt{V_0^2 - V_f^2}$$

where V_0 and V_f are the velocities before and after the principal impact, respectively.

95th-Percentile Velocity Change

A statistical value indicating the velocity change which occurs during the time of the principal impact forces. Up to 95 percent of the survivable mishaps occur at or below this velocity change level.

Flight Mishap

A mishap in which there was $10,000 or greater Department of Defense (DOD) aircraft damage or loss of a DOD aircraft, and intent for flight for DOD aircraft existed at the time of the mishap. Other property damage or injury or death may or may not have occurred (from OPNAV Instruction P3750.6N, Reference 4).

Accident

A flight mishap in which the aircraft damage and/or injury was directly related to the principal impact forces.

Ditching

A flight mishap that results from a forced landing on water. The impact force do not cause the loss of the aircraft although the aircraft may have been subsequently lost due to other causes.

Low-Severity Accident

A flight mishap resulting in at least substantial structural damage and one or more major injuries to the occupants.

Significant Survivable Accident

A flight mishap resulting in at least substantial structural damage and one or more major injuries to the occupants. All the accidents in the sample used to develop the data base were significant survivable accidents.

Nonsurvivable Accident

A flight mishap in which the impact acceleration environment exceeded the limits of human tolerance, and/or the occupied volume was compromised. Postcrash fire alone was not considered a justifiable cause to classify an accident as nonsurvivable.

Injury Classification

Injuries were classified and appropriate costs assigned according to the categories contained in OPNAV Instruction P3750.6N (Reference 4) as follows:

a. Alfa - Fatal injury. An injury that results in death from a mishap or the ensuing complications, regardless of the length of time intervening between the mishap and a subsequent death.

b. Bravo - Permanent total disability. Any nonfatal injury that, in the opinion of competent medical authority, permanently and totally incapacitates a person to the extent that he or she cannot follow any gainful occupation. In addition, the loss, or the loss of use, of both hands, both feet, both eyes, or a combination of any of these body parts as a result of a single mishap is considered a permanent total disability.

c. Charlie - Permanent partial disability. An injury that does not result in death or permanent total disability but, in the opinion of competent medical authority, results in permanent impairment or loss of any part of the body, the loss of the great toe, the thumb, or an irreparable inguinal hernia, with the following exceptions:

- Teeth
- The four smaller toes
- Distal phalanx of any finger
- Distal two phalanges of the little finger
- Repairable hernia
- Hair, skin, nails, or any subcutaneous tissue.

d. Delta - An injury that does not result in death, permanent total disability, or permanent partial disability, but does result in one or more lost workdays (not including the day of the injury).

e. Echo - Bodily harm requiring more than first aid (but not involving a lost workday).

f. Foxtrot - Bodily harm requiring only first aid, or no treatment.

g. Golf - No bodily harm.

h. Lima - Lost at sea.

i. Uniform - Missing/unknown.

PART I: HELICOPTERS

HELICOPTER ACCIDENT SAMPLE

The accident sample consisted of all (184) helicopter flight mishaps of Navy and Marine Corps helicopters which occurred during the calendar years 1972 to 1981, a 10-year evaluation period. Table 2 shows the breakdown according to helicopter type and basic mission classification (i.e., attack, search and rescue, utility, cargo, antisubmarine). Six major series of aircraft were considered in this study: AH-1, H-1, H-2, H-3, H-46, and H-53. A distinction was made between the AH-1 and H-1 series (HH-1, TH-1, UH-1) due to significant differences in mission requirements, flight characteristics, and fuselage structure.

Accident Statistics

The accidents for the six major aircraft series were classified according to three levels of accident severity: low severity, significant survivable, and nonsurvivable. (Definitions for these classifications can be found in the previous section.) Table 3 shows the distribution of accidents according to severity and occurrence on land and water. The key accidents considered in this study were the 37 significant survivable water accidents and 64 significant survivable land accidents. Note that all 184 accidents had to be reconstructed in order to make the determination of accident severity. However, more time was spent analyzing the impact conditions and injuries in the significant accidents. The relatively large number of low-severity water mishaps is attributable to the poor stability of a floating helicopter. Many of these mishaps were the result of an aircraft that sank after a successful and uneventful ditching or water landing.

Table 4 shows a comparison between actual accidents on water and ditchings classified as flight mishaps when landing on water due to aircraft damage. For example, the H-3 series aircraft had a total of 33 flight mishaps occurring during the evaluation period. Fourteen of these occurred on water with impact forces significant enough to be classified as an accident in this study. An additional 12 mishaps were the result of aircraft ditchings; in 10 of these the aircraft subsequently sank due to lack of flotation or buoyancy. For all six series, 32 out of 40, or 80 percent, of the helicopters that ditched at sea (and were classified as a flight mishap with a minimum of $10,000 damage) subsequently sank, resulting in total loss. Although this finding is not specifically crashworthiness related, it is significant in terms of the cost and reduction in readiness associated with total loss of the aircraft.

Although all of the aircraft series had mishaps occurring both on land and water, in most cases, one was predominate due to the basic mission requirements. Figure 1 shows the relative percentage of mishaps occurring on land and water for each type of aircraft. The AH-1, H-1, and H-53 series had predominately land mishaps. On the other hand, mishaps in the H-2 and H-3 series occurred mainly on water. Mishaps in the H-46 series were almost evenly divided between occurrences on water and land.

The number of persons receiving major and fatal injuries in helicopter accidents was greatly influenced by the number of land impacts. A total of 271 out of 389, or 69 percent, of the major injuries and fatalities occurred in land impacts. Figure 2 shows the number of persons receiving these serious

Table 2. Summary of Navy and Marine Helicopter Flight Mishaps, 1972-1981, by Model

Series	Model	No. of Mishaps*	Series	Model	No. of Mishaps*
AH-1	AH-1J	8	H-3	HH-3A	3
	AH-1S	1		SH-3A	3
	AH-1T	6		SH-3D	10
		15		SH-3G	5
				SH-3H	12
H-1	HH-1K	5			33
	TH-1L	4			
	UH-1E	11	H-46	CH-46D	22
	UH-1H	3		CH-46E	1
	UH-1N	22		CH-46R	8
		45		HH-46A	5
					36
H-2	HH-2D	5			
	SH-2D	3	H-53	CH-53A	11
	SH-2F	10		CH-53D	24
	UH-2C	1		CH-53E	1
		19			36

*Total helicopter mishaps: 184

Table 3. Navy and Marine Helicopter Flight Mishaps Categorized by Helicopter Type and Accident Severity

	Water Mishaps			Land Mishaps			
Series	Low Severity	Significant Survivable	Nonsurvivable	Low Severity	Significant Survivable	Nonsurvivable	Total
AH-1	1	1	2	0	8	3	15
H-1	6	3	0	11	20	5	45
H-2	4	9	1	1	2	2	19
H-3	16	6	4	1	4	2	33
H-46	7	13	1	2	8	5	36
H-53	2	5	2	2	22	3	36
TOTAL	36	37	10	17	64	20	184

Table 4. Water-Related Accidents and Ditchings in Navy and Marine Helicopter Flight Mishaps, 1972-1981

Series	Total Number of Mishaps	Number of Water-Related Accidents	Number of Ditchings: Total Number	Number of Ditchings: Number of Aircraft Lost
AH-1	15	4	0	0
UH-1	45	3	6	6
H-2	19	7	7	5
H-3	33	14	12	10
H-46	36	11	10	8
H-53	36	4	5	3
TOTAL	184	43	40	32

injuries for each helicopter series. The H-53, H-46, and H-1 series predominate in terms of numbers of major injuries and fatalities with 148, 83, and 64, respectively.

TERRAIN

Terrain at the impact site was tabulated from the flight surgeon's report. This listing of impacted terrain by helicopter series is presented in Table 5. The following trends can be seen in the terrain data for the combined sample:

- 45.3 percent occurred on water
- 36.1 percent occurred on flat ground
- 18.6 percent occurred in or through trees, or onto uneven ground.

These percentages are significant in terms of design of specific aircraft components. For example, in the aggregate of all helicopter series, the landing gear may have functioned as an absorber of impact energy in 36.1 percent of the impacts occurring on relatively flat ground. However, for the H-53 and H-1 series, the gear had the opportunity to function in 55 and 53 percent of the accidents, respectively, while a similar comparison for the H-3 series would be 12 percent.

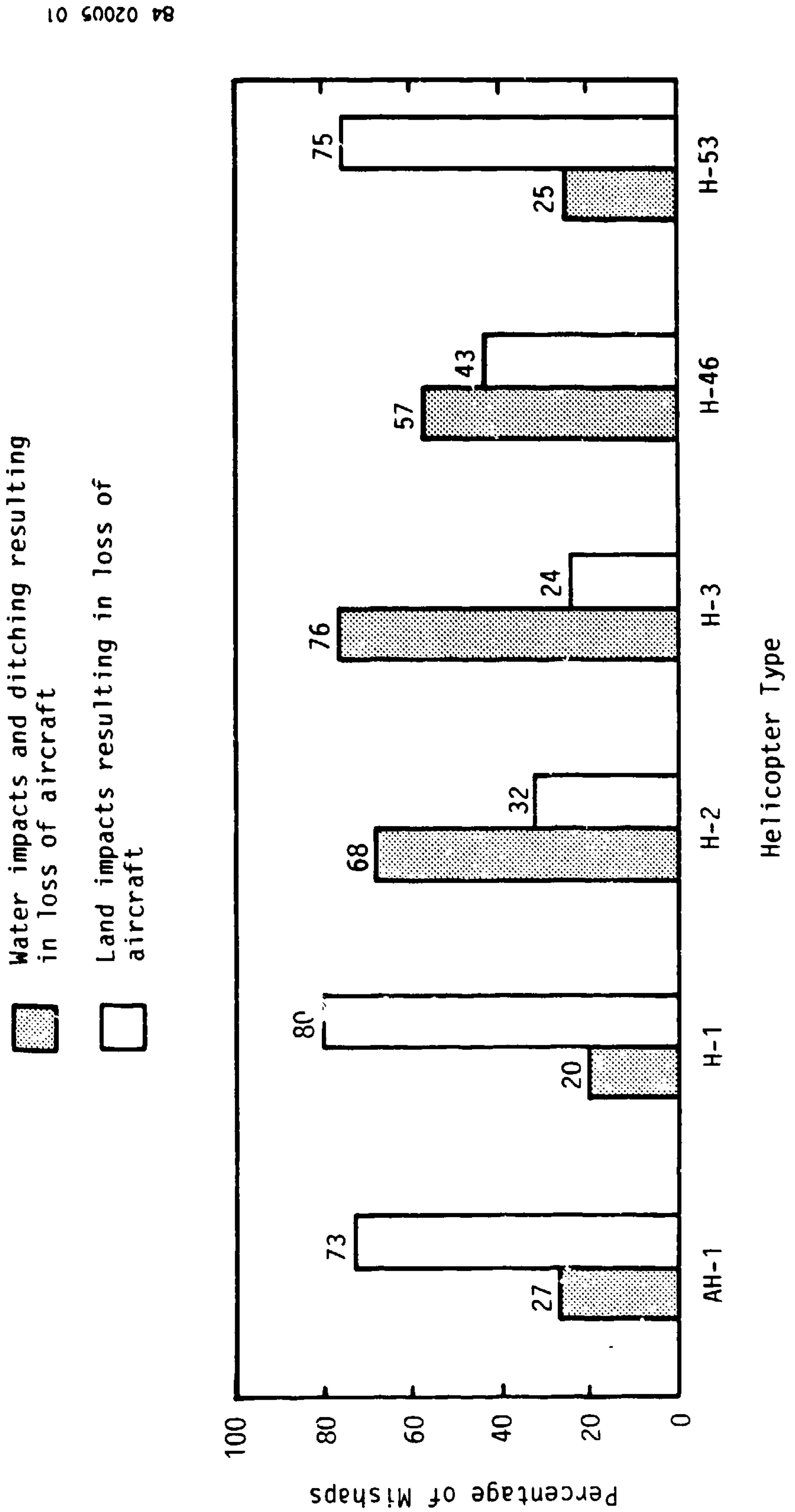

Figure 1. Distribution of Flight Mishaps According to Helicopter Type.

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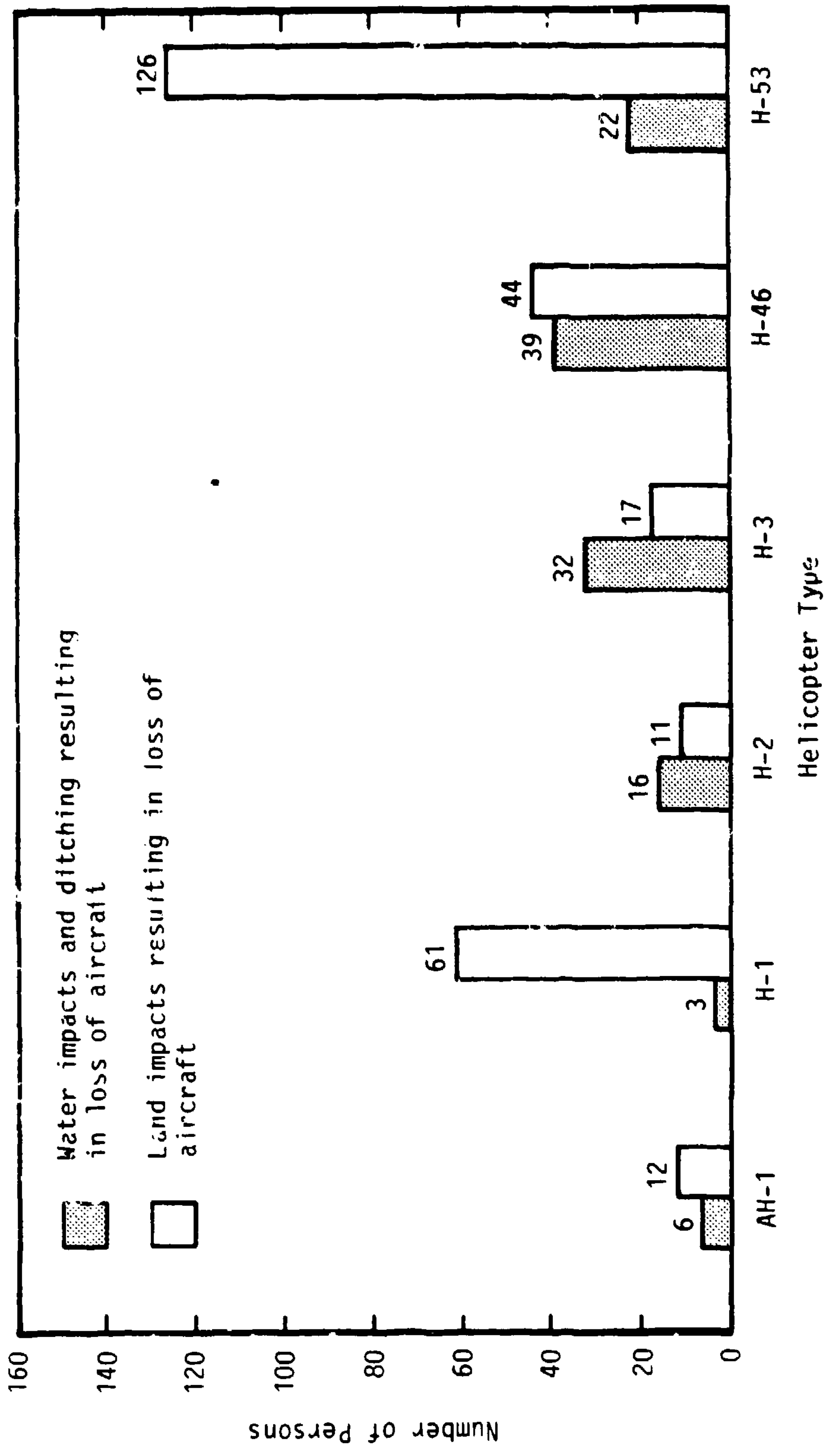


Figure 2. Number of Persons Receiving Major and Fatal Injuries in Navy and Marine Helicopter Flight Mishaps.

Table 5. Terrain at Impact Site as Classified in Flight Surgeon's Report

	Number of Occurrences by Helicopter Model						
Terrain Classification	AH-1	UH-1	H-2	H-3	H-46	H-53	Total
Open Sea		4	14	25	18	9	70
River	1	1					2
Deep Water	1	3			1		5
Shallow Water	2	2		1	2		7
Deep Snow		1					1
Marsh/Swamp/Mud		1				1	2
Soft Ground	2	9	1	1	2	4	19
Dense Woods		1				2	3
In Trees					1		1
Through Trees	2	2	1		3	1	9
Ravine/Steep Slope	1	6	1	1	3	2	14
Rocks				2	1	1	4
Desert	2	1		1		3	7
Hard Ground	4	12		2	4	11	33
Runway		2	2			1	5
Flight Deck					1	1	2
TOTAL	15	45	19	33	36	36	184

HELICOPTER IMPACT PARAMETERS

Impact parameters were estimated during the accident evaluation effort from the helicopter orientation and velocity at the instant prior to the principal impact. Estimates of orientation and velocity were based on occupant and witness statements, knowledge of the mission, helicopter performance characteristics, and structural damage at impact. It was not always possible to determine these estimates for every accident case; however, there was a sufficient number of accidents with estimated impact parameters to develop a statistical description of the accident environment.

ORIENTATION AT IMPACT

The distribution of impact angles was based on 101 significant survivable accidents with at least one known angle. Pitch, roll, and yaw angles are defined as angular deviations about the three mutually perpendicular aircraft axes, as illustrated in Figure 3. The impact angle is defined as the angle between the flight path velocity vector and the impacted surface.

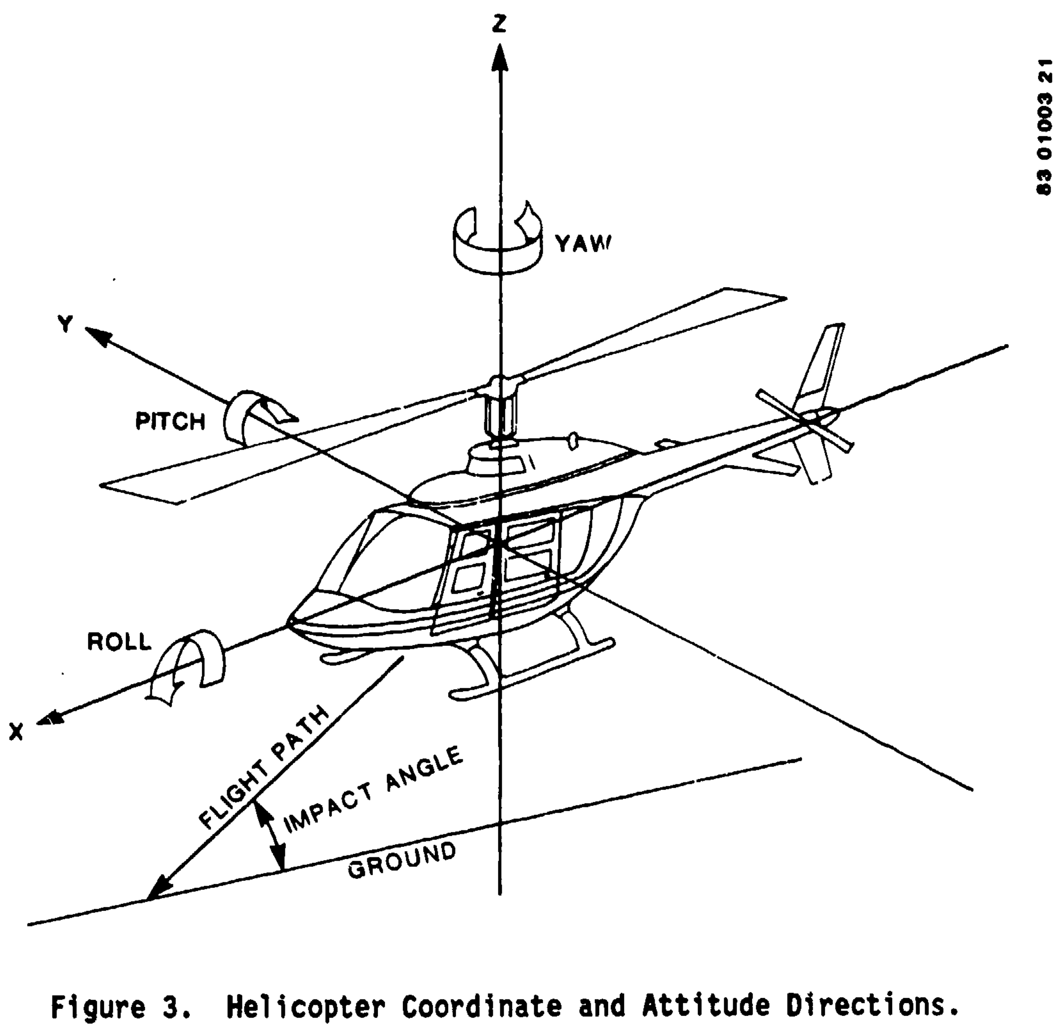


Figure 3. Helicopter Coordinate and Attitude Directions.

Pitch Angle

The distribution of pitch angle magnitude and direction is listed in Table 6. Approximately 67 percent of the impacts occurred between -10 and +10 degrees pitch, and 87 percent occurred between ±20 degrees. Thirty-six impacts occurred with upward, or positive, pitch, compared to 24 with a negative pitch angle. The trend toward a greater percentage of accidents with positive pitch angles is expected due to the flaring maneuver used to arrest or reduce an excessive sink rate prior to impact.

Table 6. Distribution of Pitch Angle and Direction at Impact for Survivable Navy and Marine Helicopter Accidents on Land and Water

Angle (deg)	Number of Accidents Per Direction			Total Accidents	Percent of Accidents	Cumulative Percent
	Up	Level	Down			
0		33		33	35.5	35.5
1-10	17		12	29	31.2	66.7
11-20	14		5	19	20.4	87.1
21-30	2		3	5	5.4	92.5
31-45	2		3	5	5.4	97.9
46-60	0		0	0	0.0	97.9
61-75	1		1	2	2.1	100.0
76-90	0		0	0	0.0	
91-120	0		0	0	0.0	
121-150	0		0	0	0.0	
151-180	0		0	0	0.0	
TOTAL				93	100.0	
Unknown				8		

Roll Angle

The distribution of roll angle at impact, shown in Table 7, exhibited a surprising trend: a "left-wing" low attitude was more common than "right-wing" low attitude. However, this trend is not believed to be significant and is attributed to the limited sample size. Sixty-eight percent of the impacts had roll angles of less than 10 degrees. A total of 78 percent had roll angles of less than 20 degrees.

Table 7. Distribution of Roll Angle and Direction at Impact for Survivable Navy and Marine Helicopter Accidents on Land and Water

Angle (deg)	Number of Accidents Per Direction: Left	Level	Right	Total Accidents	Percent of Accidents	Cumulative Percent
0		55		55	58.5	58.5
1-10	5		4	9	9.6	68.1
11-20	7		2	9	9.6	77.7
21-30	5		1	6	6.4	84.1
31-45	2		3	5	5.3	89.4
46-60	2		0	2	2.1	91.5
61-75	1		1	2	2.1	93.6
76-90	1		3	4	4.3	97.9
91-120	0		0	0	0.0	97.9
121-150	0		2	2	2.1	100.0
151-180	0		0	0	0.0	
TOTAL				94	100.0	
Unknown				7		

Yaw Angle

The yaw angle at impact was more difficult to estimate than pitch and roll angle, as evidenced by the 21 accidents with unknown yaw angles (Table 8). There appeared to be two classes of accidents in the study in terms of yaw angle. Yaw was negligible in 80 percent of the accidents, most of which had tail rotor authority at impact. If tail rotor authority was lost prior to the principle impact, the yaw angle could have been anywhere between zero and 360 degrees (unless the aircraft was "streamlined" by maintaining a high airspeed). Also, these aircraft would often have a significant yaw rate at impact. The effect of the yaw rate was to displace the occupants from their normal seated position due to centrifugal force, thus reducing the tolerance of the occupants to sustain the linear impact forces. In this study several spinal injuries were noted at low vertical impact velocities (10 ft/sec) when the aircraft had a significant yaw rate.

Table 8. Distribution of Yaw Angle and Direction at Impact for Survivable Navy and Marine Helicopter Accidents on Land and Water

	Number of Accidents Per Direction				Percent	
Angle (deg)	Left	Level	Right	Total Accidents	of Accidents	Cumulative Percent
0		64		64	80.0	80.0
1-10	0		2	2	2.5	82.5
11-20	0		5	5	6.3	88.8
21-30	0		1	1	1.2	90.0
31-45	0		0	0	0.0	90.0
46-60	0		0	0	0.0	90.0
61-75	0		0	0	0.0	90.0
76-90	0		2	2	2.5	92.5
91-120	0		0	0	0.0	92.5
121-150	0		1	1	1.2	93.7
151-180	1		4	5	6.3	100.0
TOTAL				80	100.0	
Unknown				21		

Impact Angle

The distribution of impact angle is shown in Table 9. There is an approximately even distribution between 0 and 60 degrees. However, almost 45 percent of the survivable accidents occur between 60 and 90 degrees with predominately vertical impact forces.

Table 9. Distribution of Impact Angle for Survivable Navy and Marine Helicopter Accidents on Land and Water

Angle (deg)	Total Number	Percent of Total (%)	Cumulative Percent (%)
0	4	4.3	4.3
1-10	11	12.0	16.3
11-20	8	8.7	25.0
21-30	8	8.7	33.7
31-45	14	15.2	48.9
46-60	6	6.5	55.4
61-75	11	12.0	67.4
76-90	30	32.6	100.0
TOTAL	92	100.0	
Unknown	9		

IMPACT VELOCITY CHANGE

The distribution of impact velocity change is based on the 101 significant survivable accidents used to define the impact angles. Cumulative frequency curves are presented in this section for impacts on both land and water and are compared to similar curves published for Navy and Marine helicopter accidents from 1969 to 1971 (Reference 1). The 95th-percentile velocity change level is also shown for each curve. This level is shown because it has been traditionally selected for design of crashworthy features for military aircraft.

Longitudinal Velocity Change

Figures 4 and 5 show the cumulative frequency distribution for the longitudinal velocity change on land and water, respectively. In both figures, the 1972-1981 data shows a distribution that occurs at lower velocities than the 1969-1971 data. This is believed to be due to more realistic estimates of velocity change based on improvements in reconstruction techniques, more complete accident reports, and a larger sample size. It should not be interpreted as a decrease in survivability between the helicopter fleets in 1969-1971 and in 1972-1981.

The 95th-percentile survivable longitudinal impact velocity change was 55 ft/sec for land impacts and 72 ft/sec for water impacts. In comparison, the U.S. Army Aircraft Crash Survival Design Guide (Reference 5) shows that 50 ft/sec is the 95th-percentile survivable longitudinal velocity change for Army rotary- and light, fixed-wing aircraft. The Army data is for the 1971 to 1976 period, and features predominately land impacts (98 percent). Therefore, there is very good agreement between the survivable impact velocity for Navy and Marine land accidents and Army accidents.

Vertical Velocity Change

The vertical velocity change curves for land and water impacts are shown in Figures 6 and 7, respectively. There is close agreement of the land accident data between the current study (1972-1981 data) and the previous Navy crash environment study (1969-1971). The 95th-percentile survivable vertical velocity change component was found to be 38 ft/sec for land accidents and 39 ft/sec for water accidents. In comparison, Army data (Reference 5) indicates that 42 ft/sec is the 95th-percentile survivable accident level.

Lateral Velocity Change

Lateral velocity change distributions for both land and water accidents are shown in Figure 8. There were no curves published in Reference 1 for a comparison of the 1969-1971 accident sample. The 95th-percentile level of 29 ft/sec for land impacts compares favorably with the Aircraft Crash Survival Design Guide recommendation of 25 ft/sec for cargo and attack helicopters and 30 ft/sec for other rotary-wing aircraft.

PITCH AND ROLL ANGLE VERSUS VERTICAL VELOCITY CHANGE

It is advantageous to have an understanding of the distribution of pitch and roll angles for various vertical velocity changes in order to optimize a vertical energy absorption system consisting of landing gear, fuselage, and seats. Figure 9 shows the distribution of all land accidents plotted according to pitch angle and vertical velocity change. Figure 10 shows a similar distribution for roll angle versus vertical impact velocity.

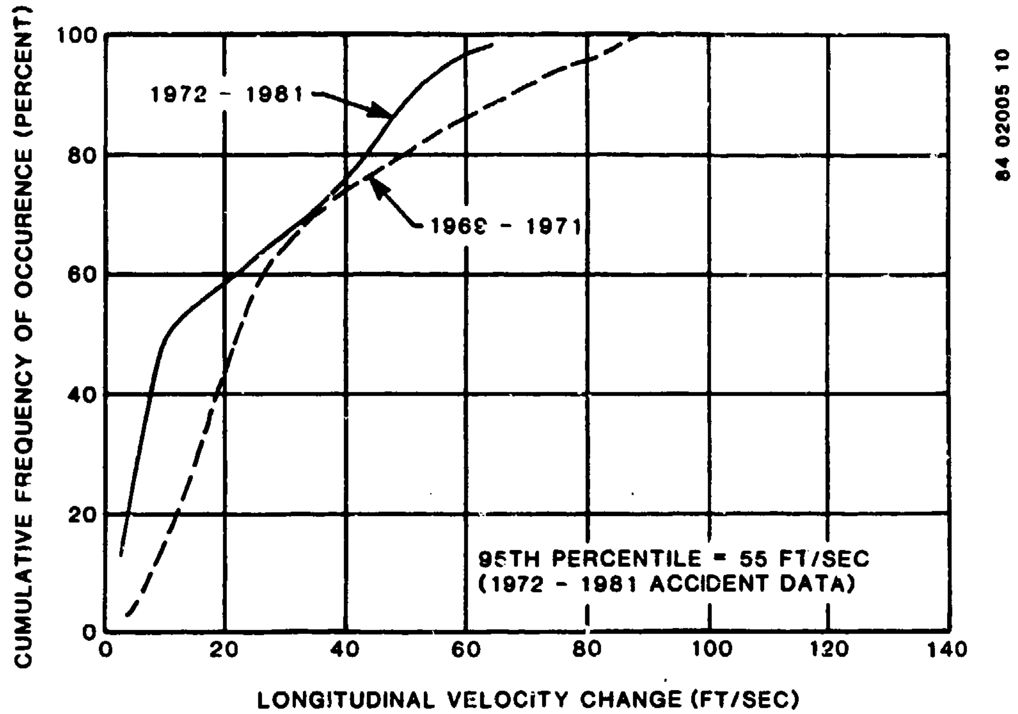


Figure 4. Cumulative Frequency Curves for Longitudinal Velocity Change in Survivable Land Accidents.

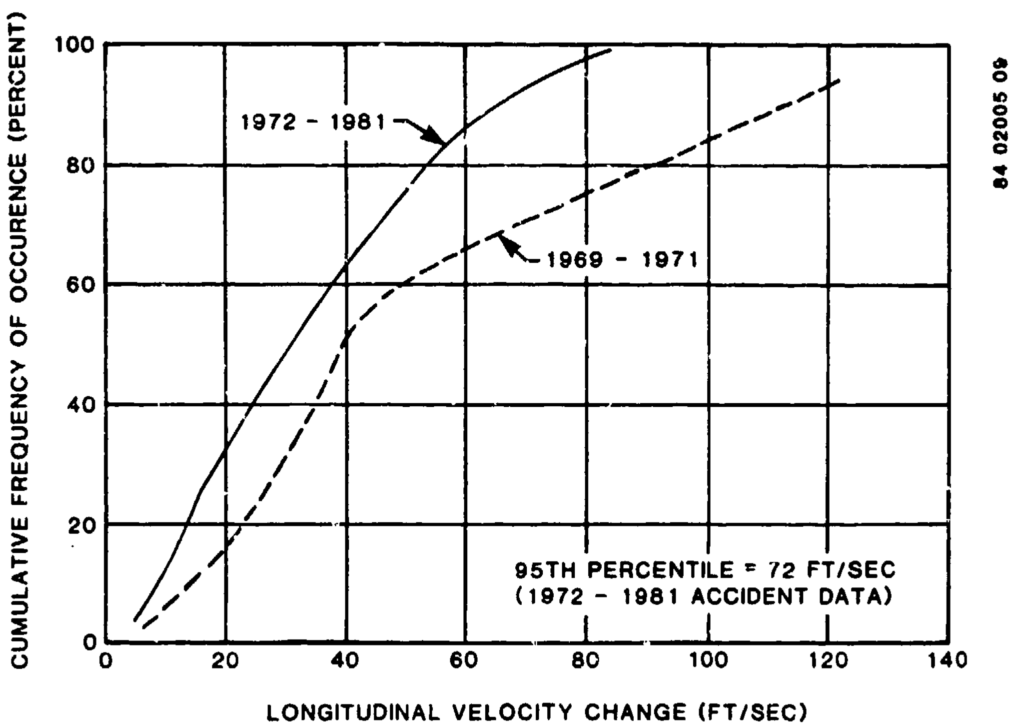


Figure 5. Cumulative Frequency Curves for Longitudinal Velocity Change in Survivable Water Accidents.

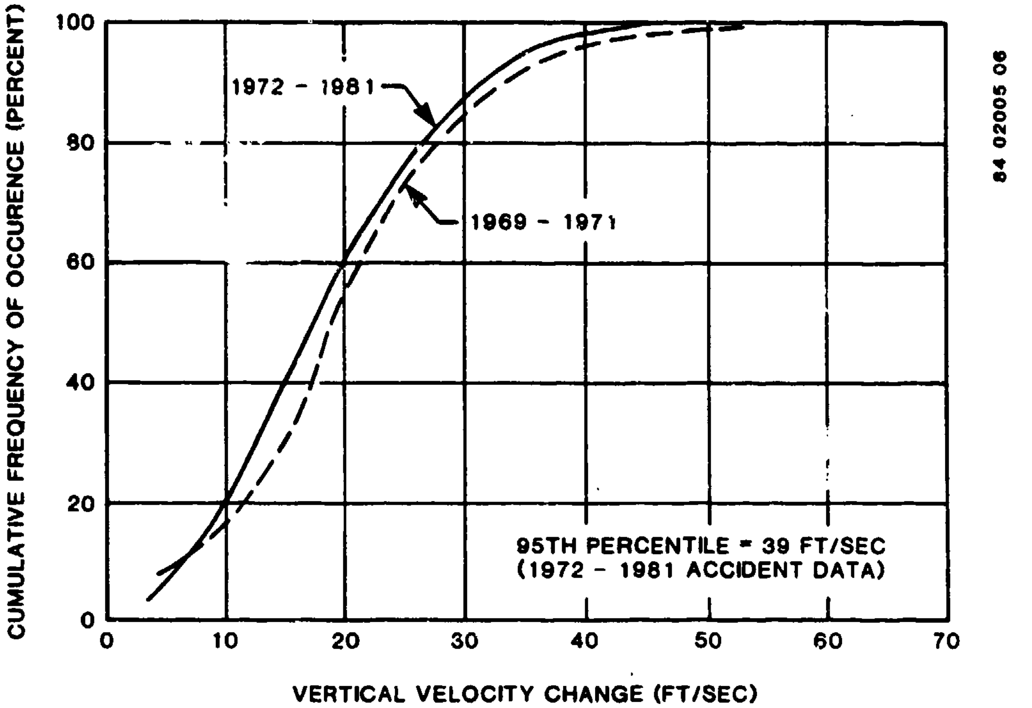


Figure 6. Cumulative Frequency Curves for Vertical Velocity Change in Survivable Land Accidents.

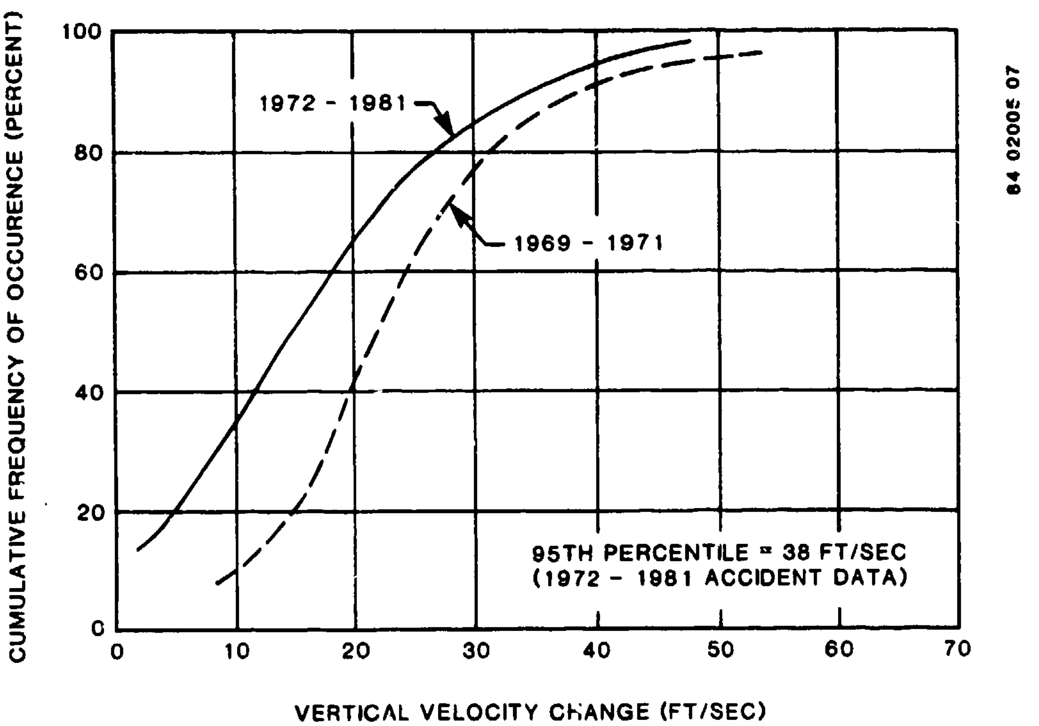


Figure 7. Cumulative Frequency Curves for Vertical Velocity Change in Survivable Water Accidents.

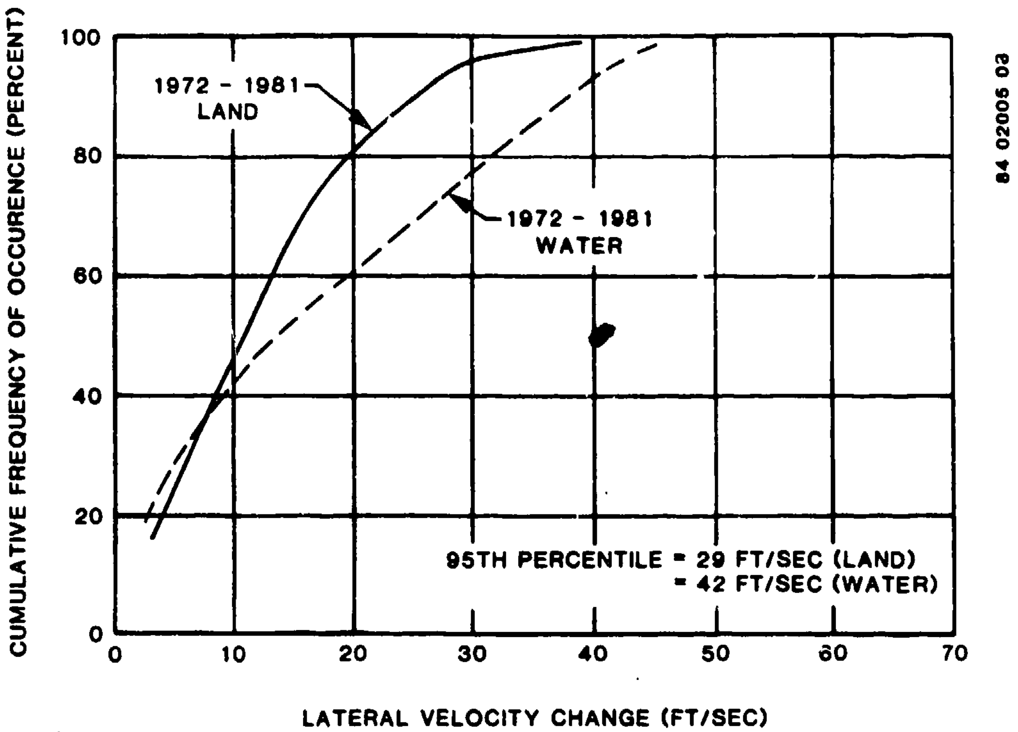
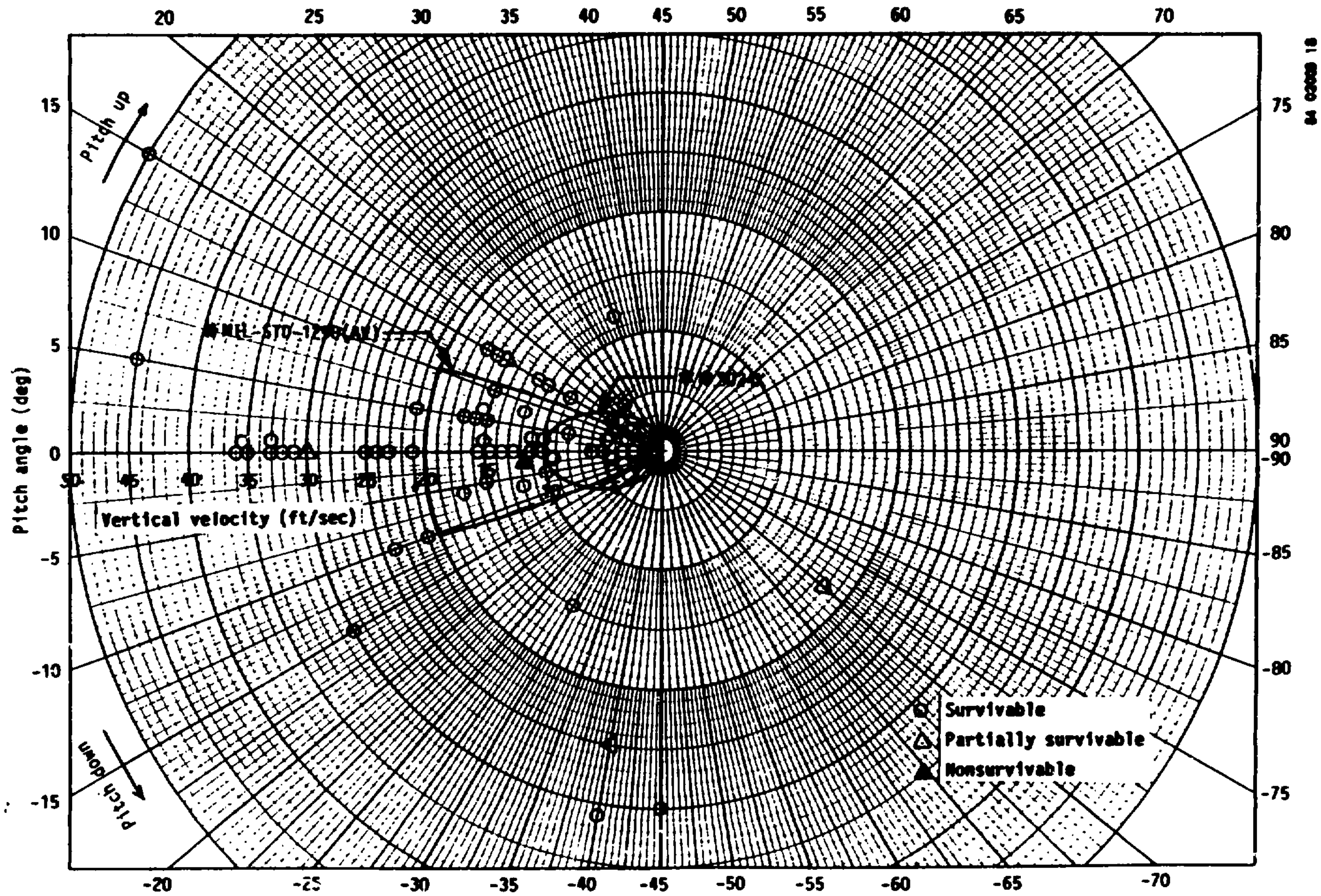


Figure 8. Cumulative Frequency Curves for Lateral Velocity Change in Survivable Land and Water Accidents.

To illustrate the use of these graphs, the landing gear design requirements contained in SD24K (Reference 6) and MIL-STD-1290(AV) (Reference 7) are shown superimposed on the helicopter accident points. The curves superimposed on Figures 9 and 10 correspond respectively to the design requirements for the generation of aircraft examined in this study (AH-1, H-1, H-2, H-3, H-46, and H-53) and the latest generation of aircraft designed specifically for crashworthiness (UH-60A and AH-64A, SH-60B*). The protective benefit of the MIL-STD-1290(AV) requirement is evident in the number of land accidents (Figures 9 and 10), in which fuselage contact and significant damage to the airframe could have been prevented.

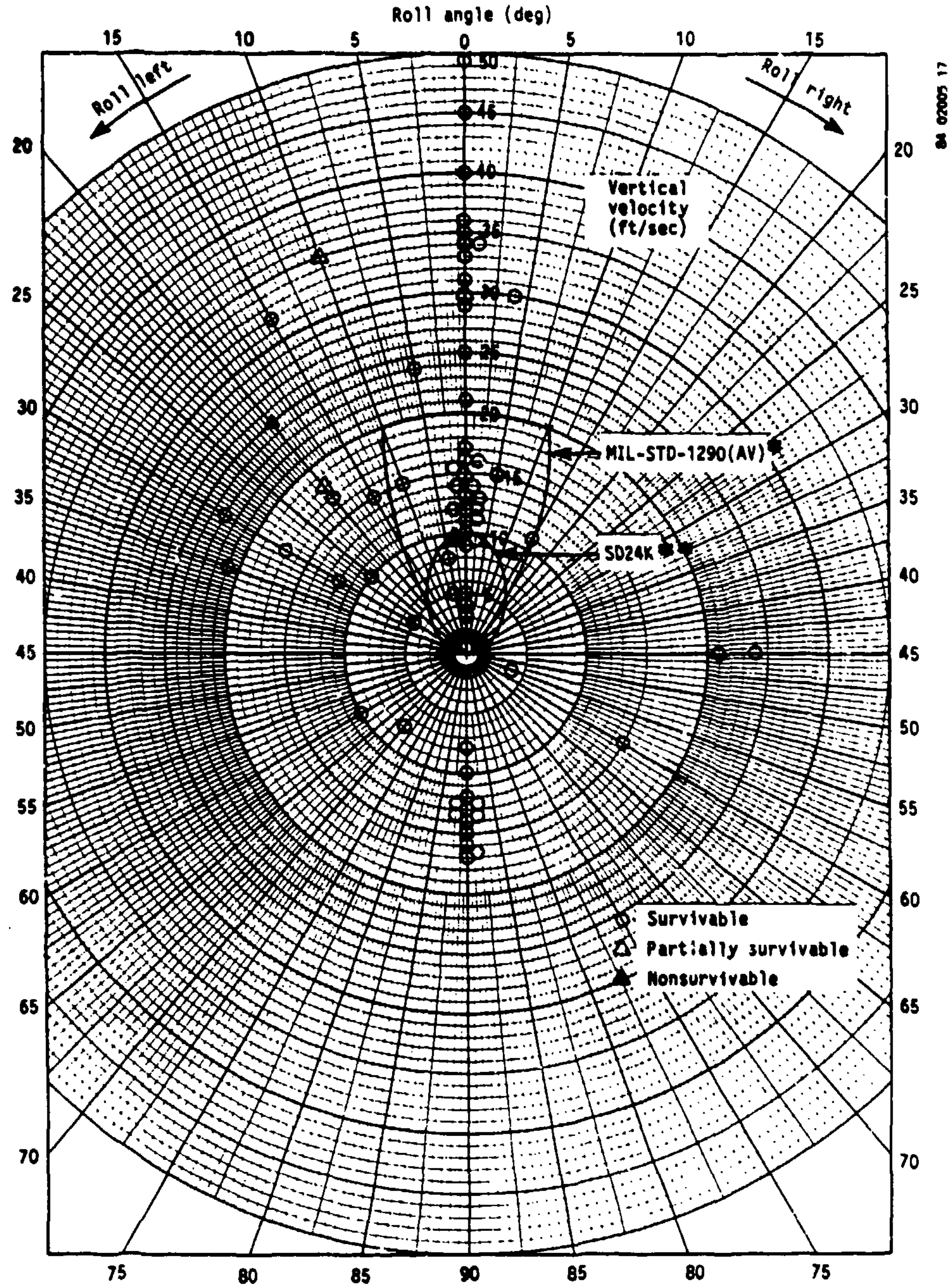
*The landing gear for the SH-60B were designed for ship landing criteria; however, the gear performance is improved over that found on older generation noncrashworthy aircraft.



*MIL-STD-1290(AV) - current landing gear design requirements.

**SD4K - landing gear design requirement for the generation of helicopters incorporated in this study.

Figure 9. Distribution of Land Accidents According to Pitch Angle and Vertical Velocity Change at Impact.



*MIL-STD-1290(AV) - current landing gear design requirements.

**SD4K - landing gear design requirement for the generation of helicopters incorporated in this study.

Figure 10. Distribution of Land Accidents According to Roll Angle and Vertical Velocity Change at Impact.

HELICOPTER INJURY/HAZARD ANALYSIS

This section contains a summary of the number of injuries and injury rates in each of the helicopter series. During data compilation, an attempt was made during the accident reconstruction to correlate a hazard with each injury.

Tables are presented with a ranking of hazards according to estimated total costs for the 10-year study period. These hazards indicate potential areas for improved crashworthiness in Navy and Marine helicopters.

INJURY RATES

Figures 11 through 13 present the injury rates on land and water for the six helicopter series. The injury rates are percentages of the total number of persons on board (shown at the right of each figure) that received minor, major, and fatal injuries. Figures 11 through 13 correspond to the injury rates for pilots and copilots, crew chiefs and crewmembers, and passengers, respectively.

The major injury and fatality rate for pilots and copilots in land mishaps (from Figure 11a) is 51 percent, or 104 major injuries and fatalities out of 205 occupants in all models. In comparison, the major injury and fatality rate in water mishaps for pilots and copilots is 34 percent. It appears from the data that the chance of injury in water accidents is lower than in land accidents. However, this is not necessarily the case, since the water mishap sample contains a significant number of low-severity ditchings which bias the data. It is believed that the injury rates in significant water accidents are similar to the rates for land accidents.

The major injury and fatality rate for crew chiefs and crewmembers in land mishaps (from Figure 12a) is 55 percent; the rate for passengers is 52 percent. It is somewhat surprising that the major injury and fatality rates for the three occupant groups are so similar considering that the hazard analysis showed that the cause of injury for these groups differed considerably.

Helicopter Occupant Injury Patterns

Injuries were compiled from all survivable accidents and included all impact-related injuries except burns, drowning, and multiple extreme injuries. The injuries were categorized into seven body areas: head, neck, legs, arms, back, chest, and abdomen. A percentage of occurrence was calculated based on the total number of injuries recorded. The results can be seen in Figures 14 through 20, which show the injury patterns for each helicopter as well as all helicopters combined. The combined results show that the head, legs, and arms have the greatest susceptibility to injury but that the rate of injury to these body parts has declined since better aircrew equipment, such as helmets and Nomex* suits, have come into wider use (compared to data tabulated in Reference 1). The sites of injuries have shifted mainly to the back and neck, indicating a need for energy-absorbing seats to reduce the spinal load of the occupants.

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*Nomex is a registered trademark of E. I. Du Pont de Nemours & Co., Inc.

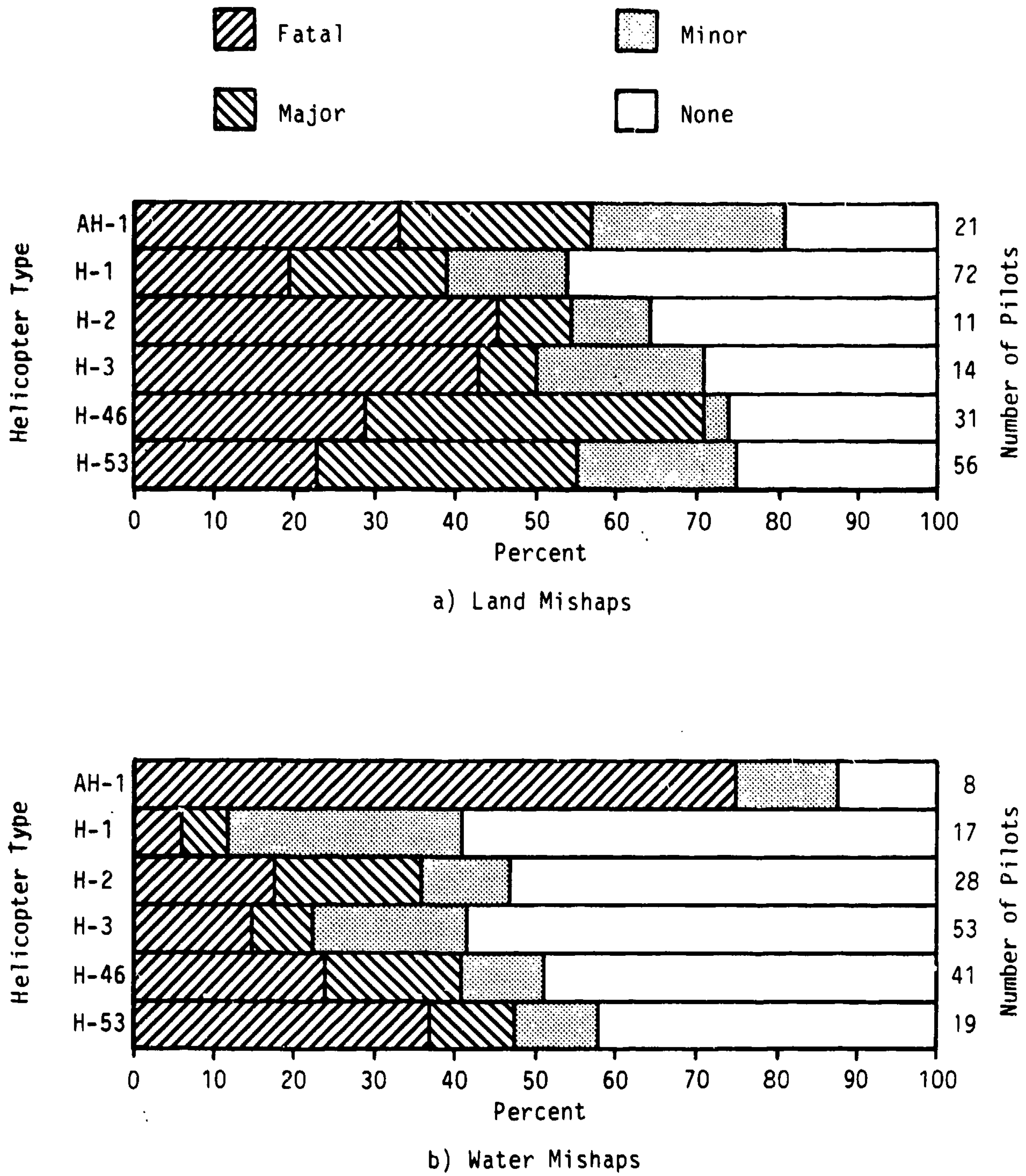

Figure 11. Distribution of Injury Severity for Pilots and Copilots Involved in Navy and Marine Helicopter Flight Mishaps.

84 02005 04

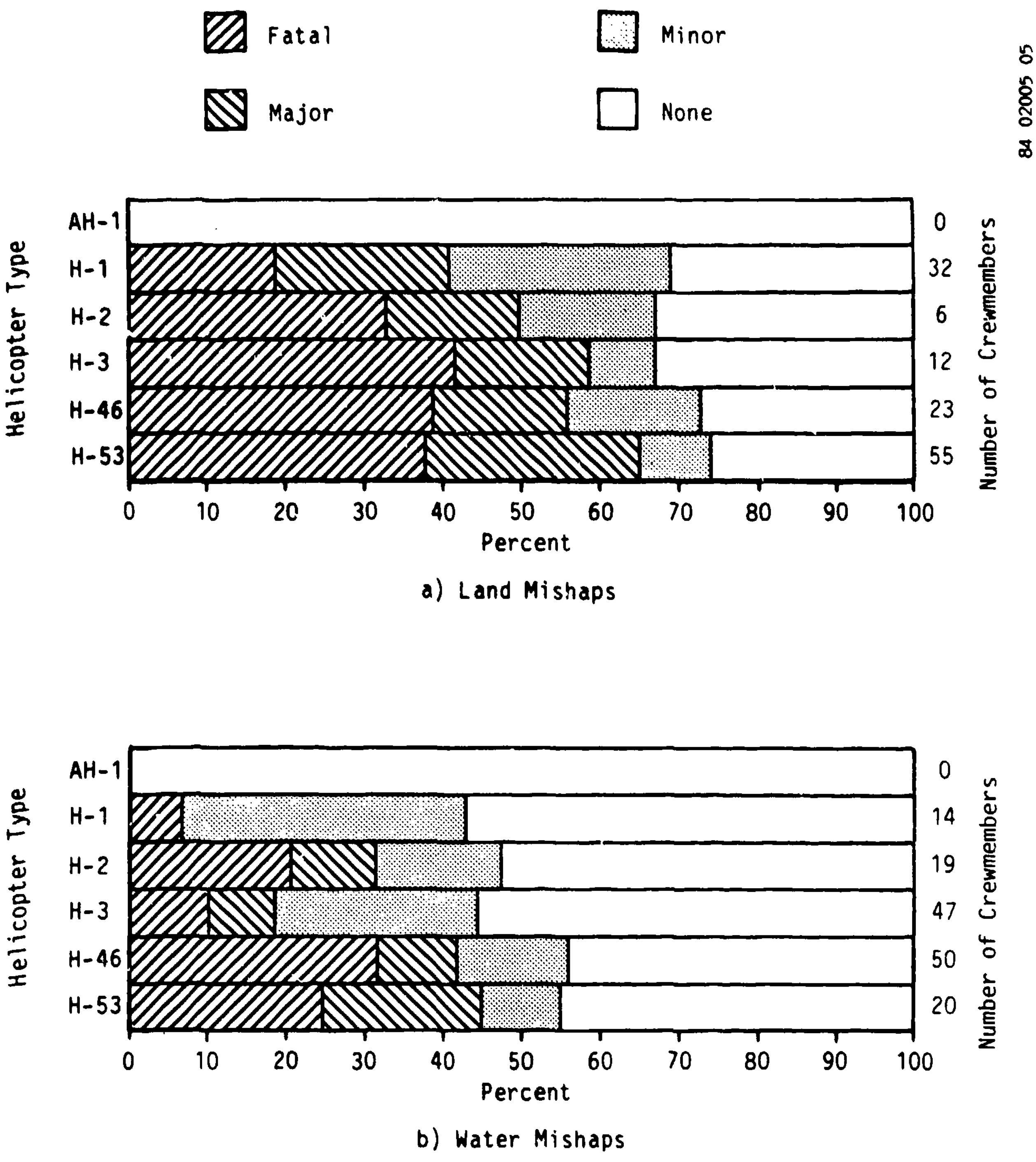

Figure 12. Distribution of Injury Severity for Crew Chiefs and Crewmembers Involved in Navy and Marine Helicopter Flight Mishaps.

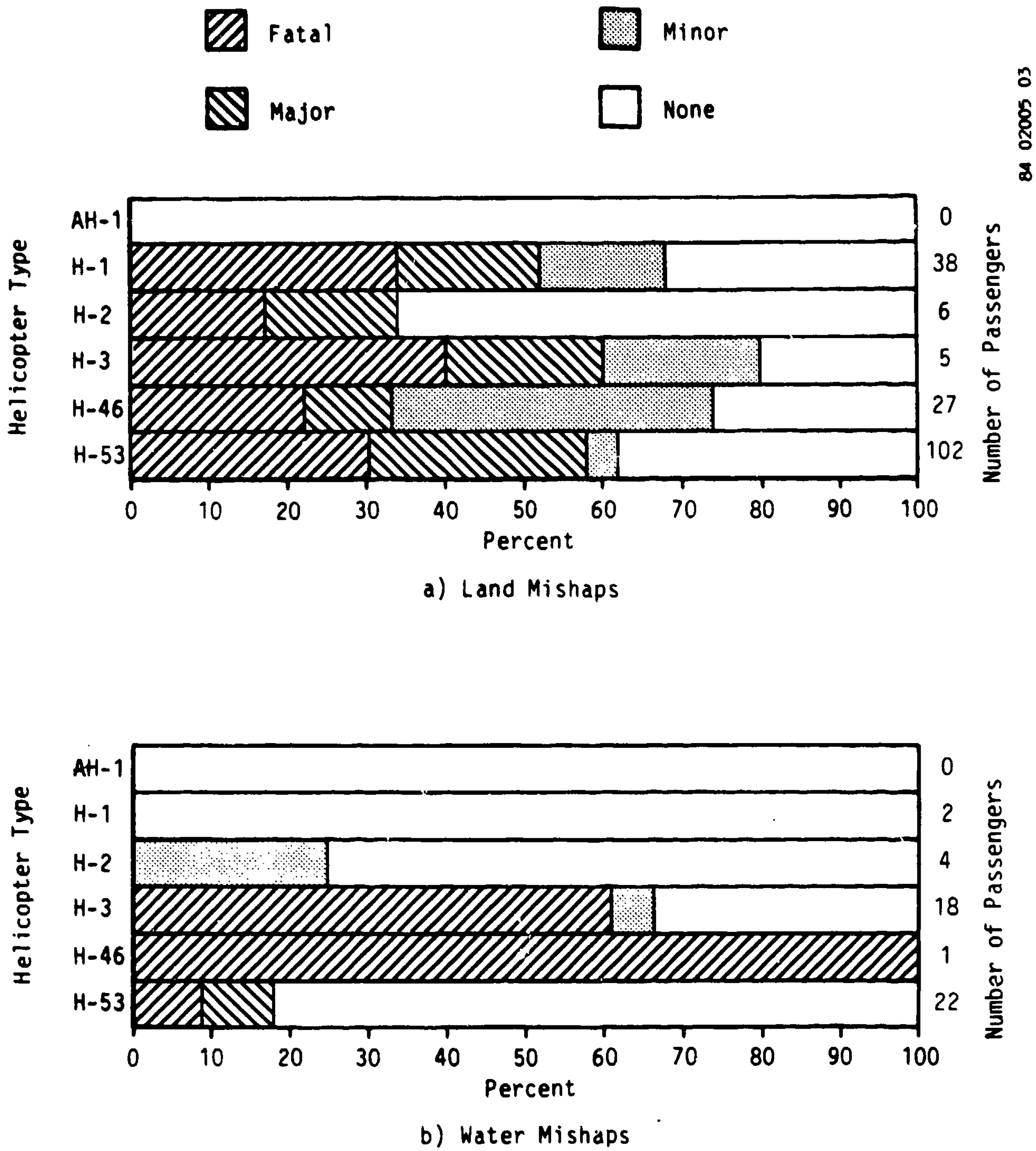

Figure 13. Distribution of Injury Severity for Passengers Involved in Navy and Marine Helicopter Flight Mishaps.

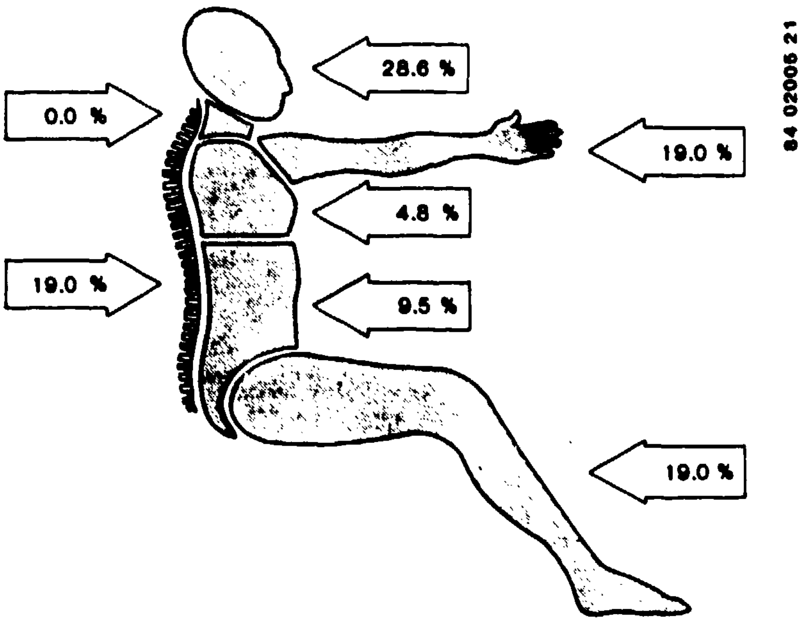

Figure 14. Injury Pattern for Naval Helicopter Occupants in the AH-1 Series (Based on 21 Recorded Injuries).

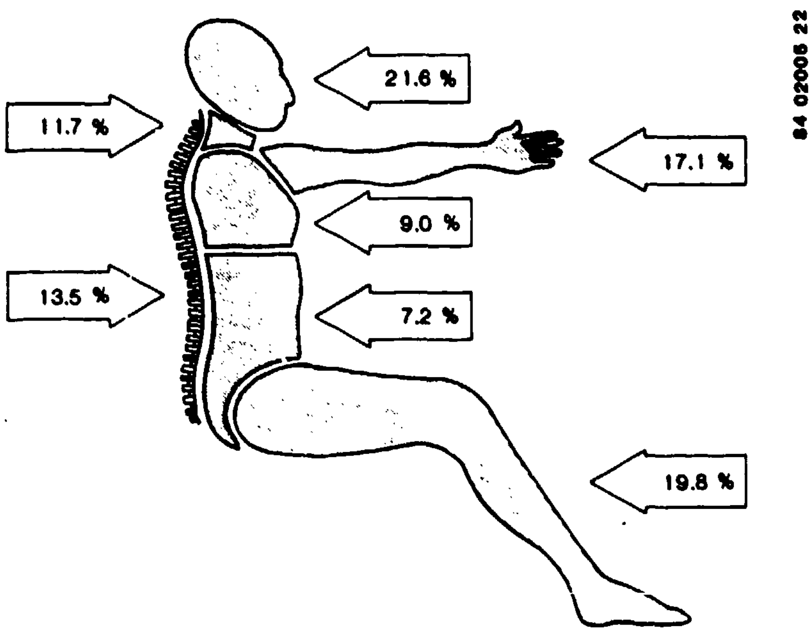

Figure 15. Injury Pattern for Naval Helicopter Occupants in the UH/HH-1 Series (Based on 111 Recorded Injuries).

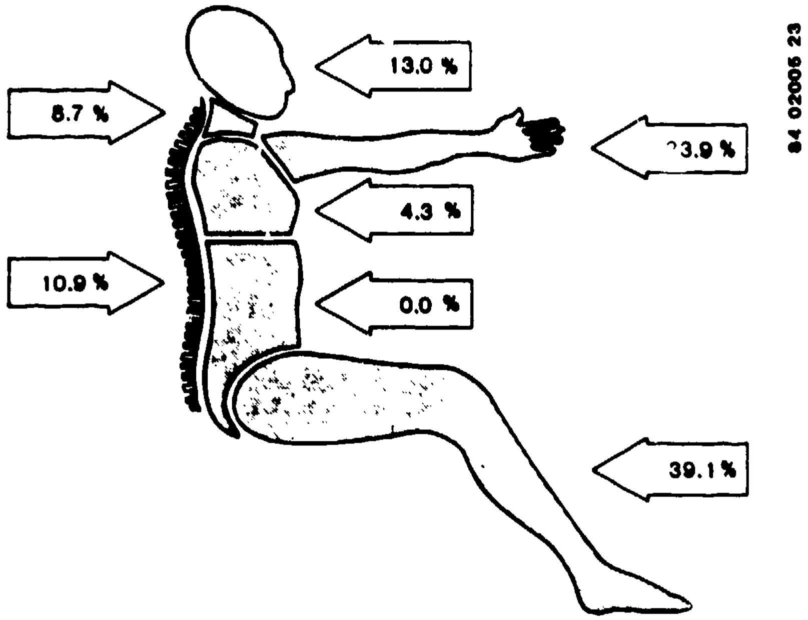

Figure 16. Injury Pattern for Naval Helicopter Occupants in the H-2 Series (Based on 46 Recorded Injuries).

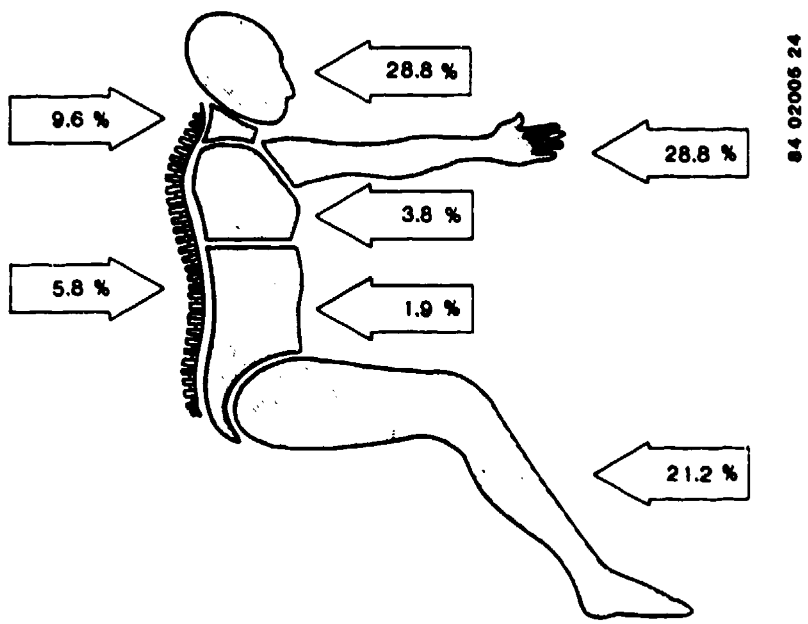

Figure 17. Injury Pattern for Naval Helicopter Occupants in the H-3 Series (Based on 52 Recorded Injuries).

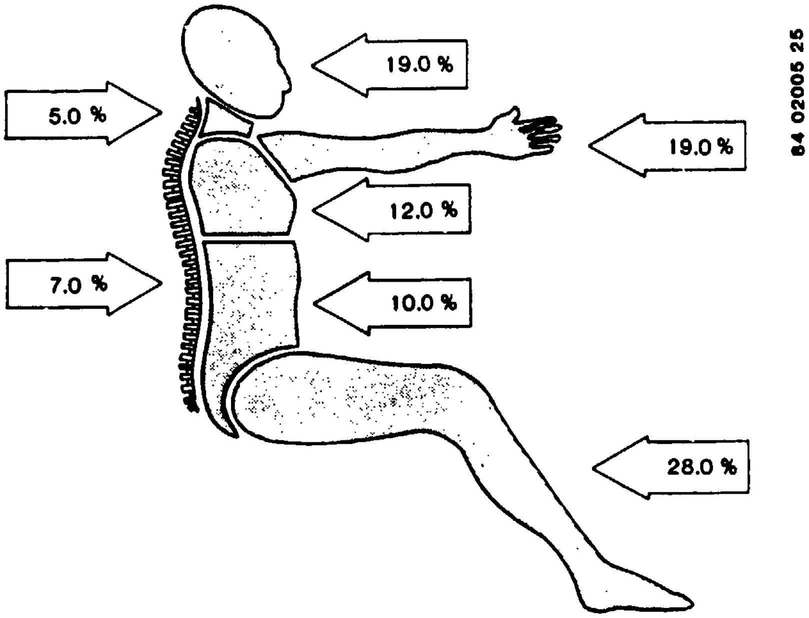

Figure 18. Injury Pattern for Naval Helicopter Occupants in the H-46 Series (Based on 100 Recorded Injuries).

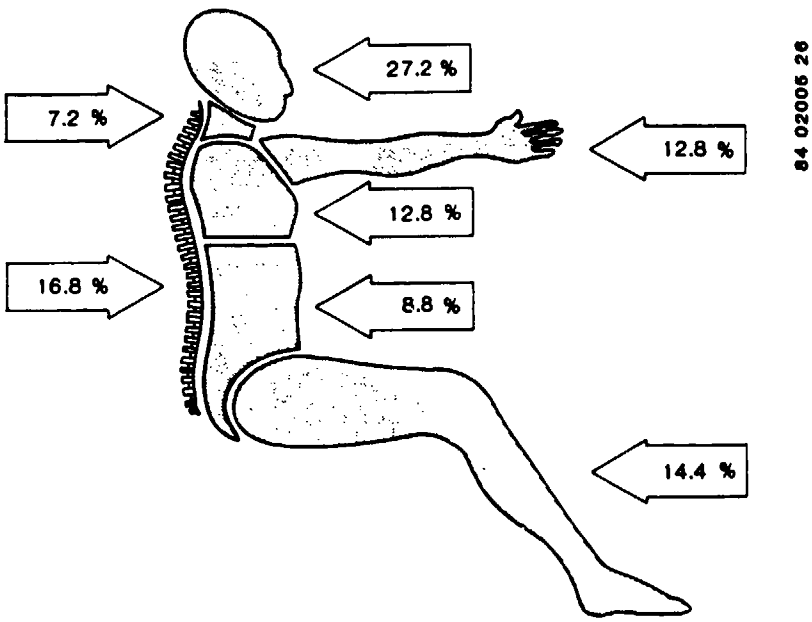

Figure 19. Injury Pattern for Naval Helicopter Occupants in the H-53 Series (Based on 125 Recorded Injuries).

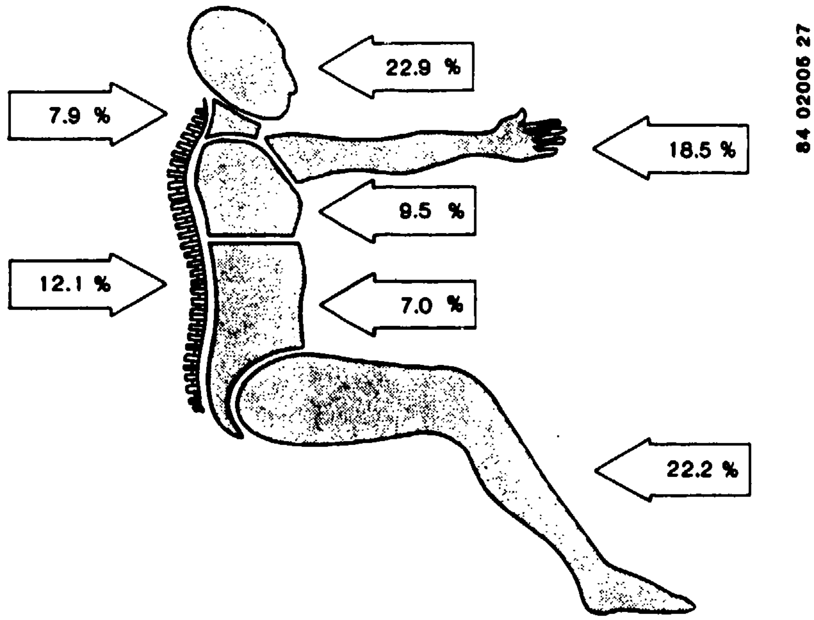

Figure 20. Injury Pattern for Naval Helicopter Occupants in All Helicopter Series Combined (Based on 455 Recorded Injuries).

Some trends in the individual helicopters show areas that may need special attention. A very high percentage of leg injuries occur in the H-2, indicating that any structure or equipment in the leg strike envelope needs better padding. The H-3 has the same problem for the arm and head strike envelopes, indicating that the console needs better padding. Back and neck injuries are particularly high in both the UH/HH/TH-1 and the H-53, indicating a need for energy-absorbing seats.

HELICOPTER HAZARD ANALYSIS

A systematic technique developed by the U.S. Army Safety Center for evaluating crash hazards in U.S. Army aircraft was adapted for this study (Reference 8). The methodology used in this technique is to tabulate the following four items:

1. Medical description of the trauma
2. Mechanism by which it occurred
3. Underlying hazard which caused the trauma
4. Resulting cost.

Injury cost data were based on the values listed in OPNAV Instruction P3750.6N (Reference 4). The cost of injuries by severity is summarized in Table 10, and the actual cost table from OPNAV Instruction P3750.6N is included as Appendix A.

Table 10. Injury Cost Data Based on OPNAV Instruction P3750.6N (Reference 4)

Injury Type	Flying Officer ($)	Other Officers ($)	Enlisted Personnel ($)	Civilian Employees ($)	Foreign Nationals ($)
Alfa Injury	330,000	150,000	47,000* 102,000**	174,000	102,000
Bravo Injury	476,000	321,C00	190,000	146,000	148,000
Charlie Injury	80,000	55,000	43,000	96,000	67,000
	3 days hospitalization, 10 lost workdays				
Delta Injury	3,035	3,035	2,335	2,125	1,800
	1 day hospitalization, 2 lost workdays				
Echo Injury	785	785	635	575	500
	1 lost workday				
Foxtrot Injury	170	170	120	100	75
Golf Injury	0	0	0	0	0

*Non-aircrew
**Aircrew

The costs for Alfa, Bravo, and Charlie injuries are taken directly from Table A-1, Appendix A. The injury costs for Delta, Echo, and Foxtrot injuries were based on costs for days hospitalized and lost workdays, using the equation for number of days as shown in Table 10. Whenever multiple injuries were present, the following formula was used to calculate the cost of the individual injury:

$$\text{Individual Cost of Injury} = \text{Total Cost of Casualty} \times \frac{\text{Cost of individual injury acting alone}}{\text{Sum of costs of all injuries each acting alone}}$$

Appendix A also contains a listing of specific injuries found in the helicopter accident analysis according to their severity classification. The injury costs tabulated using the methodology above and presented in this report are in 1982 fiscal year dollars for all injuries occurring during the 10-year (1972-1981) evaluation period.

Sixteen specific hazards were identified as causes of injuries in this study. They are ranked in Table 11 according to the total cost of injuries produced in all models. The total cost of injuries in survivable accidents was estimated to be $25.0 million. Almost one-quarter of this amount, $6.4 million, was attributable to seat structural failures allowing the occupant to impact aircraft structure. The second most prevalent hazard was postcrash fires causing thermal injuries, which accounted for $4.2 million of the total injury cost. An additional $23.8 million worth of injury costs were accrued in accidents considered to be nonsurvivable*. The total cost of all injuries (in survivable and nonsurvivable accidents) during the 10-year period was $48.9 million.

The number of persons receiving major or fatal injuries attributable to the 16 hazards are listed in Table 12. Two hundred ninety-four persons received injuries of these severities in survivable accidents, all due to causes presented in this study. The H-53, H-46, and H-1 series aircraft had the greatest number of major injuries and fatalities in survivable accidents with 133, 64, and 49, respectively. Because of the highly nonlinear relationship between injury cost and injury severity, the total number of major injuries and fatalities for each hazard (shown in the last column of Table 12) does not have the same descending progression as the total cost in Table 11. With this in mind, Table 13 was developed to summarize and prioritize the potential areas for improved crashworthiness in Navy and Marine helicopters.

The most serious crash hazard resulted from failure of the structural integrity of crew and troop seats. This problem was noted repeatedly in accident reports as an inherent problem in several of these helicopter models. However, it is being addressed through retrofit programs of seats with enhanced structural integrity and energy absorption capabilities.

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*It is expected that as new aircraft are introduced to the fleet and older models are upgraded, the level of survivability will increase, and thus reduce the injury potential in these accidents.

Table 11. Injury Costs Attributable to 16 Hazards in Survivable Navy and Marine Helicopter Accidents

Hazard No.	Hazard Description	Injury Costs in Survivable Accidents - by Helicopter Series (in Thousands of Dollars) AH-1	H-1	H-2	H-3	H-46	H-53	Total Injury Cost for Hazard ($)
1	Body struck aircraft structure when seat failed	0	915	5	812	2,180	2,518	6,430,700
2	Body exposed to fire when fuel system failed on impact	0	813	0	801	90	2,533	4,236,950
3	Body drowned because injuries prevented escape from aircraft	250	250	352	479	1,136	0	2,467,000
4	Body struck by external object when main rotor blade entered occupiable space	330	0	0	0	826	762	1,917,615
5	Body received excessive decelerative force when aircraft and seat allowed excessive loading	161	668	163	2	239	474	1,707,590
6	Body struck aircraft structure while not restrained during impact	0	50	0	3	195	1,209	1,457,330
7	Body struck aircraft structure when gunner's belt allowed excessive motion	0	156	147	0	409	550	1,262,340
8	Body struck aircraft structure when structure collapsed excessively	80	166	83	0	818	0	1,147,175
9	Body drowned due to unknown causes	0	0	330	141	549	0	1,020,000
10	Body struck aircraft structure when restraint failed	476	1	0	2	45	43	567,705

Table 11 (Contd). Injury Costs Attributable to 16 Hazards in Survivable Navy and Marine Helicopter Accidents

Hazard No.	Hazard Description	Injury Costs in Survivable Accidents - by Helicopter Series (in Thousands of Dollars) AH-1	H-1	H-2	H-3	H-46	H-53	Total Injury Cost for Hazard ($)
11	Body drowned due to underwater egress difficulties	0	0	432	0	0	0	432,000
12	Upper body struck structure because restraint was not used properly	0	330	0	2	0	0	331,540
13	Body struck by external object when external object (other than main rotor blade) entered occupiable space	80	3	2	0	80	0	165,760
14	Upper body struck structure because restraint allowed excessive motion	0	6	1	1	3	97	108,255
15	Body injured during postcrash egress	0	3	1	8	6	2	20,495
16	All other injury causes (missing aircraft, unknown or unclassified injuries, and injuries suffered during rescue)	382	680	5	49	9	659	1,783,971
TOTAL INJURY COST IN SURVIVABLE ACCIDENTS								25,056,516
TOTAL INJURY COST IN NONSURVIVABLE ACCIDENTS								23,851,000
TOTAL INJURY COST								48,907,516

Table 12. Number of Major Injuries and Fatalities Attributable to 16 Hazards in Survivable Navy and Marine Helicopter Accidents

Hazard No.	Hazard Description	Number of Major Injuries and Fatalities in Survivable Accidents - by Helicopter Series						Total Number of Major Injuries & Fatalities
		AH-1	H-1	H-2	H-3	H-46	H-53	
1	Body struck aircraft structure when seat failed	0	4	2	6	11	19	42
2	Body exposed to fire when fuel system failed on impact	0	9	0	5	3	33	50
3	Body drowned because injuries prevented escape from aircraft	1	1	2	3	6	0	13
4	Body struck by external object when main rotor blade entered occupiable space	1	0	0	0	7	3	11
5	Body received excessive decelerative force when aircraft and seat allowed excessive loading	2	13	3	0	4	9	31
6	Body struck aircraft structure while not restrained during impact	0	1	0	1	5	44	51
7	Body struck aircraft structure when gunner's belt allowed excessive motion	0	5	3	0	6	9	23
8	Body struck aircraft structure when structure collapsed excessively	1	4	2	0	6	0	13
9	Body drowned due to unknown causes	0	0	1	3	7	0	11

Table 12 (Contd). Number of Major Injuries and Fatalities Attributable to 16 Hazards in Survivable Navy and Marine Helicopter Accidents

Hazard No.	Hazard Description	Number of Major Injuries and Fatalities in Survivable Accidents - by Helicopter Series AH-1	H-1	H-2	H-3	H-46	H-53	Total Number of Major Injuries & Fatalities
10	Body struck aircraft structure when restraint failed	1	0	0	1	2	1	5
11	Body drowned due to underwater egress difficulties	0	0	2	0	0	0	2
12	Upper body struck structure because restraint was not used properly	0	1	0	0	0	0	1
13	Body struck by external object when external object (other than main rotor blade) entered occupiable space	1	1	1	0	1	0	4
14	Upper body struck structure because restraint allowed excessive motion	0	2	0	0	1	6	9
15	Body injured during postcrash egress	0	0	0	1	2	1	4
16	All other injury causes (missing aircraft, unknown or unclassified injuries, and injuries suffered during rescue)	2	8	1	2	3	8	24
TOTAL		9	49	17	22	64	133	294

Table 13. Summary of Potential Areas for Improved Crashworthiness in Navy and Marine Helicopters

Priority	Potential Areas for Improvement	Hazards Resulting	Number of Major Injuries and Fatalities in Survivable Accidents	Total 10-year Injury Cost in Survivable Accidents ($)	Predominate Models and Percentage of Total 10-year Injury Cost
1	Crew and troop seats separate from aircraft and/or transmit intolerable vertical loads to occupants	1, 5	73	8,138,290 crewseats 7,120,300 troop seats 1,017,990	H-53 (37%) H-46 (30%) H-1 (19%) H-3 (10%)
2	Fuel systems fail on impact resulting in postcrash fire with subsequent thermal injuries to occupants	2	50	4,236,950	H-53 (60%) H-1 (19%) H-3 (19%)
3	Poor utilization of existing restraints and failure of the gunner's belt to provide effective restraint which allows secondary impacts	6, 7, 10, 12, 14	73	3,727,260	H-53 (51%) H-46 (17%) H-1 (13%)
4	Aircraft rapidly submerges after impact without permitting egress of the occupants (with and without other complicating injuries)	3, 9, 11	26	3,919,000	H-45 (43%) H-2 (28%) H-3 (16%)
5	Main rotor blade displaces downward on impact and enters occupiable space	4	11	1,917,615	H-46 (43%) H-53 (40%)

Failure of fuel systems resulting in postcrash fire was the second most serious hazard. Approximately 60 percent of the thermal injury costs during the 10-year period was attributable to one series, the H-53. However, postcrash fires were prevalent in all models. The incidence of postcrash fires in land and water flight mishaps is shown in Table 14. As might be expected, there were no postcrash fires in water impacts. The seriousness of the problem in land impacts, however, is highlighted by the fact that in 41.2 percent of the accidents (for all models) postcrash fire occurred. Table 15 compares the number of injuries and fatalities caused by fires (thermal) and all other causes (nonthermal).

Table 14. Postcrash Fire Experience in Navy and Marine Helicopters

	Land Impacts			Water Impacts		
Series	No. of Mishaps	No. of Fires	Percent Fires (%)	No. of Mishaps	No. of Fires	Percent Fires (%)
AH-1	11	5	45.4	4	0	0
H-1	36	7	19.4	9	0	0
H-2	5	1	20.0	14	0	0
H-3	7	4	57.1	26	0	0
H-46	16	9	56.3	20	0	0
H-53	27	16	59.3	9	0	0
TOTAL	102	42	41.2	82	0	0

Approximately 18 percent of the injuries and fatalities in Navy and Marine helicopters were fire related. Also shown in Table 15 is the injury experience in U.S. Army helicopters, both with and without crashworthy fuel systems (CWFS), and in the U.S. civil helicopter fleet. The incidence of thermal injuries and fatalities in Navy and Marine helicopters appears to be a severe problem, with the greatest hazard in the H-53, H-3, H-1, and AH-1 series. Surprisingly, there is a high incidence of fires in H-46 land impacts (56.3 percent), while the number of injuries and fatalities caused by fires is relatively low. It is believed that this is due to the distance between the occupants and the fuel cells, which are located externally in the sponson.

The third significant hazard relates to restraint systems, particularly poor utilization of existing equipment and the lack of crash restraint provided by the gunner's belt. These problems were most common in the large capacity helicopters, the H-53 and H-46. Failure to use existing restraints was almost entirely limited to passengers and crewmembers performing duties in the aft sections of the aircraft. The inherent restraint problems with the Navy gunner's safety belt (MS 16070) have been recognized for some time. A research and development effort was conducted by the Naval Air Development Center in 1975 and 1976 (References 11 and 12), although it is unknown if the recommended system will be incorporated into any fleet aircraft in the near future.

Table 15. Comparison of Thermal and Nonthermal Injuries and Fatalities in Survivable Land Impacts

Series	Injuries: Thermal	Injuries: Nonthermal	Fatalities: Thermal	Fatalities: Nonthermal	Percentage of Injuries and Fatalities Caused by Fire (%)
AH-1	0	10	2	5	11.8
H-1	3	55	8	22	12.5
H-2	0	5	0	8	0.0
H-3	0	9	5	8	22.7
H-46	3	33	2	22	8.3
H-3	17	64	22	43	26.7
TOTAL	23	176	39	108	17.9
U.S. Army Helicopters without CWFS* (Reference 9)	64	1,297	95	159	9.8
U.S. Army Helicopters with CWFS* (Reference 9)	5	386	0	44	1.1
U.S. Civilian Helicopters (Reference 10)	13	174	18	42	12.6

*Crashworthy fuel system

The fourth major crashworthiness hazard was drowning following a water impact, either with or without other complicating injuries. From a crashworthiness standpoint, this problem is difficult to resolve. The highest incidence of drowning was associated with the H-46 aircraft, although the problem also existed in the other predominately over-water aircraft, the H-2 and H-3. A program is underway to develop an emergency flotation system for the CH-46 helicopter, although the system will provide only a partial solution to the problem of drownings in accidents with significant impact forces. However, had these three aircraft types been equipped with emergency flotation during the period of 1972-1981, it may have been possible to save 23 aircraft (5 H-2's, 10 H-3's and 8 H-46's) which sank after successful ditchings.

The final major crash hazard was due to rotor blade strikes in occupied areas. Of the 294 occupants seriously and fatally injured, only 11 of the cases are attributable to this hazard, although the effects were often catastrophic. This hazard does not appear to be one worthy of the expenses of a retrofit program. However, consideration of this hazard in new aircraft designs may be feasible.

HELICOPTER ACCIDENT SEVERITY LEVEL ANALYSIS

Military specifications relating to the incorporation of crashworthiness in procured aircraft are based on minimizing injury up to a specific level of accident severity. The specified severity level originates from a study such as this, and takes into account the distribution of injuries, survivability, and costs.* This section reviews the distribution of injuries, postcrash fires, and injury costs for specific ranges of accident severity using the data from the 1972 to 1981 Navy and Marine helicopter accidents.

Five accident severity levels were developed for this analysis. Noted as I through V, these levels correspond approximately to 25, 50, 75, 100, and 125 percent of the 95th-percentile survivable land and water accidents. The 95th-percentile survivable level has vertical and longitudinal components of 40 and 60 ft/sec, respectively. Thus, the accident severity levels I through V correspond to 10-, 20-, 30-, 40-, and 50-ft/sec vertical velocity change components, and 15-, 30-, 45-, 60-, and 75-ft/sec longitudinal velocity change components. The injury severity and cost analysis are based on data from survivable accidents.

INJURY SEVERITY VERSUS ACCIDENT SEVERITY LEVEL

Figures 21 and 22 show the distribution of injuries and fatalities for land and water accidents, respectively. Each injury point is plotted in proximity to the appropriate location for the aircraft longitudinal and vertical velocity change at impact. The five curves representing the outer boundaries of the accident severity levels are superimposed on the injury data.

Especially in the land accidents (Figure 21), there is a progression from predominately minor or no injuries in level I to major injuries and fatalities in levels IV and V. Table 16 quantifies the effects of accident severity on injuries by showing the total number of persons involved and the rates with which they received minor, major, and fatal injuries. The expected trend of increasing injury severity with accident severity can be seen in this table. Accident severity level IV had the largest number of persons involved (148) and the most major injuries (49) and fatalities (50).

POSTCRASH FIRES VERSUS ACCIDENT SEVERITY LEVEL

The incidence of postcrash fires for the five accident severity levels are shown in Figure 23. Again, as expected, there is a trend between the percentage of accidents with postcrash fire and increasing severity levels. Table 17 presents the number of land accidents within each severity level and the percentage of those with postcrash fires.

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*For example, MIL-STD-1290(AV) is based on minimizing injuries up to the 95th-percentile survivable level in U.S. Army rotary- and light, fixed-wing aircraft.

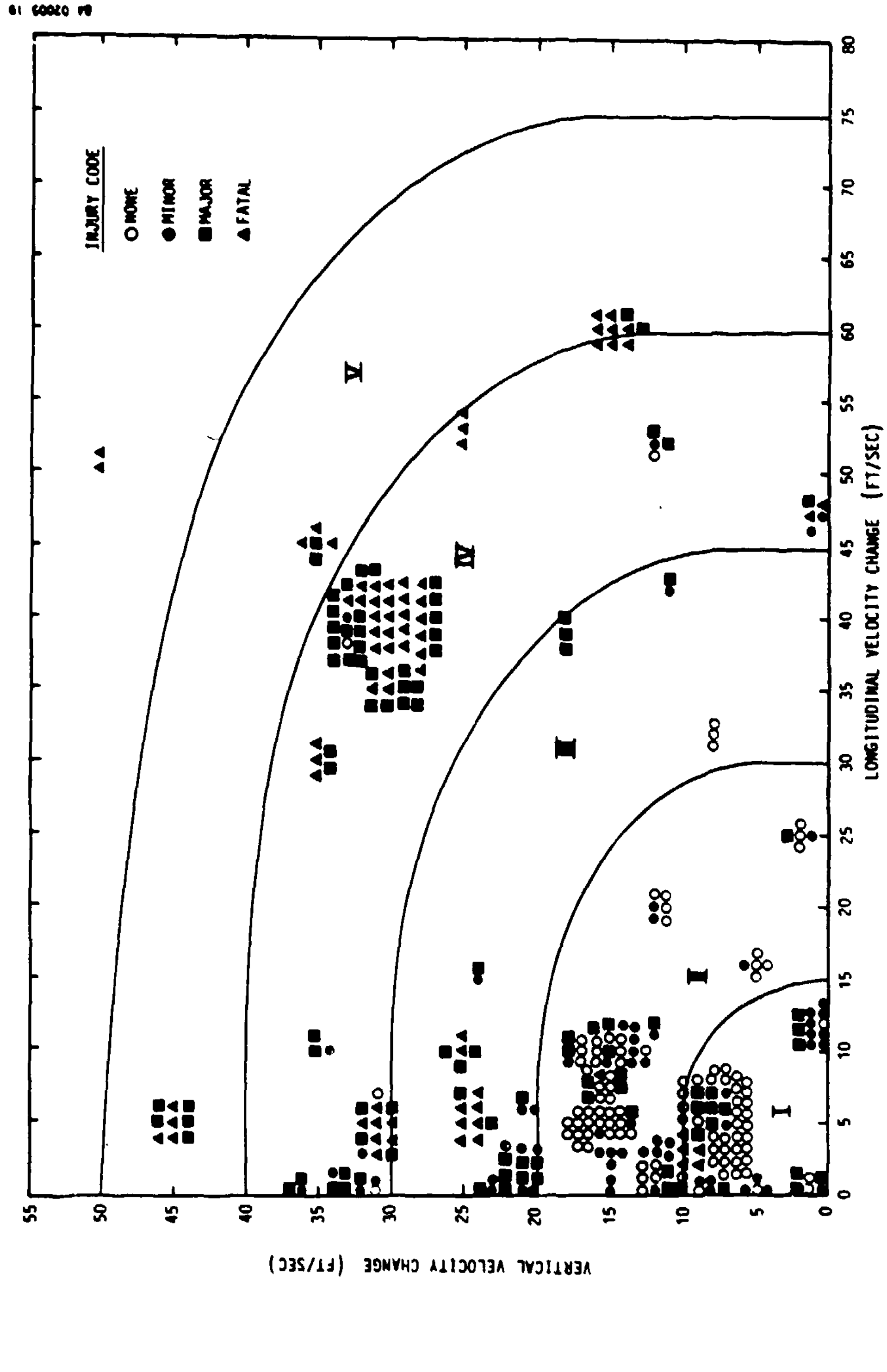


Figure 21. Distribution of Injuries According to Aircraft Impact Velocity for Survivable Land Accidents.

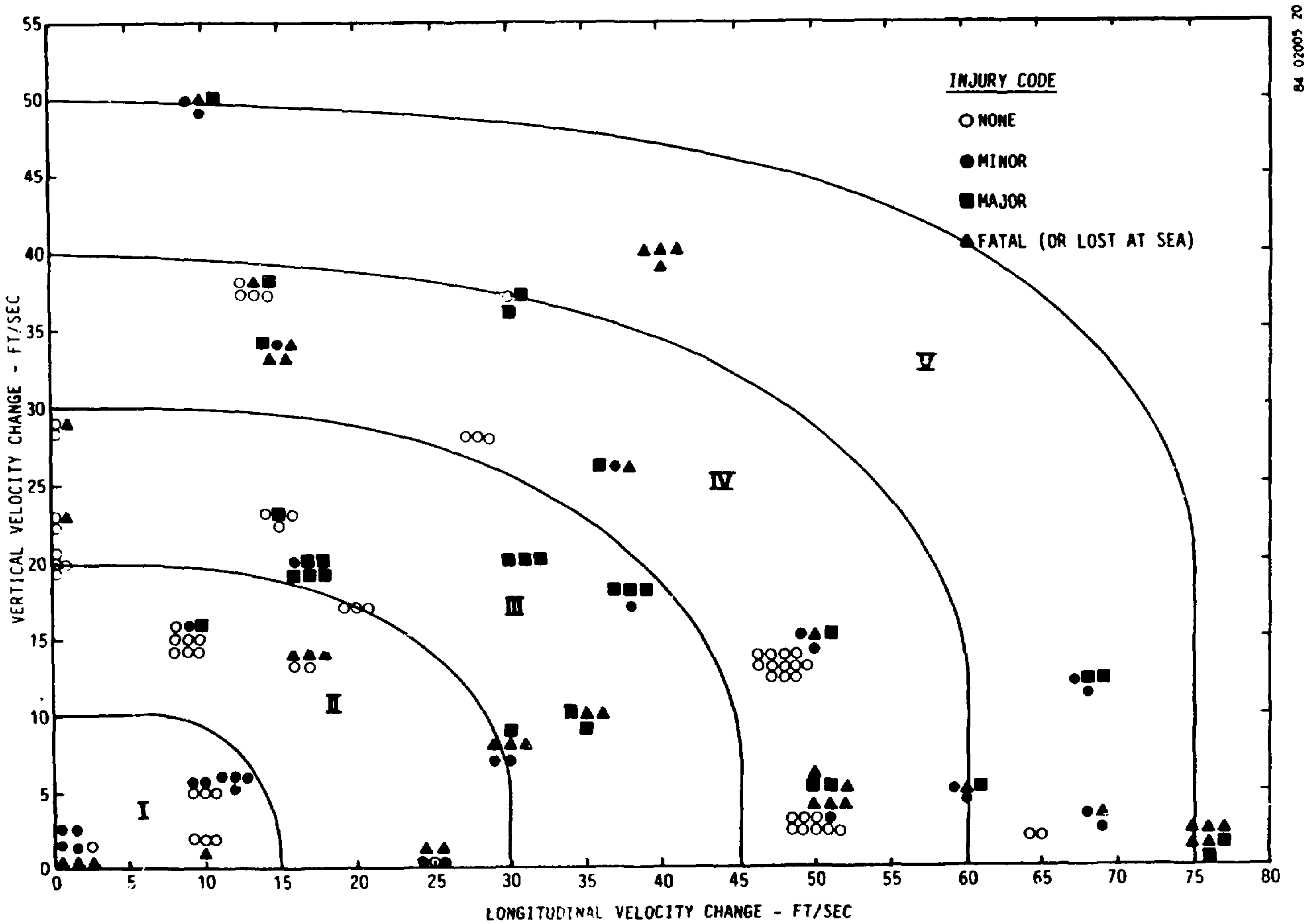


Figure 22. Distribution of Injuries According to Aircraft Impact Velocity for Survivable Water Impacts.

Table 16. Total Number of Injuries and Percentages of Injuries by Severity for Each Accident Severity Level in Land and Water Accidents

Accident Severity Level	Total Number of Persons Involved	Percentage of Persons Receiving Injuries (%)				
		None	Minor	Major	Fatal	Total
I	96	46.9	29.1	14.6	9.4	100.0
II	128	54.7	25.0	15.6	4.7	100.0
III	74	14.9	17.6	43.2	24.3	100.0
IV	148	21.6	10.1	33.8	34.5	100.0
V	45	4.4	17.8	28.9	48.9	100.0

INJURY COSTS VERSUS ACCIDENT SEVERITY LEVEL

The costs of injuries and fatalities in survivable accidents for each of the five levels are listed in Table 18. Level IV had the highest total cost ($9.5 million), representing 38 percent of the total survivable accident injury cost, and 99 out of 244 major injuries and fatalities. Levels I and II contributed a very low percentage of the injury cost. The cost per level peaks at level IV and then decreases as the number of persons involved declines. The injury costs in levels I through IV represent 65.5 percent of the total cost of the injuries in survivable accidents. As a group, these levels had 197 out of 244 major injuries and fatalities. The average cost of a major injury or fatality for all levels was:

$$\frac{\$25,056,516}{244} = \$102,691$$

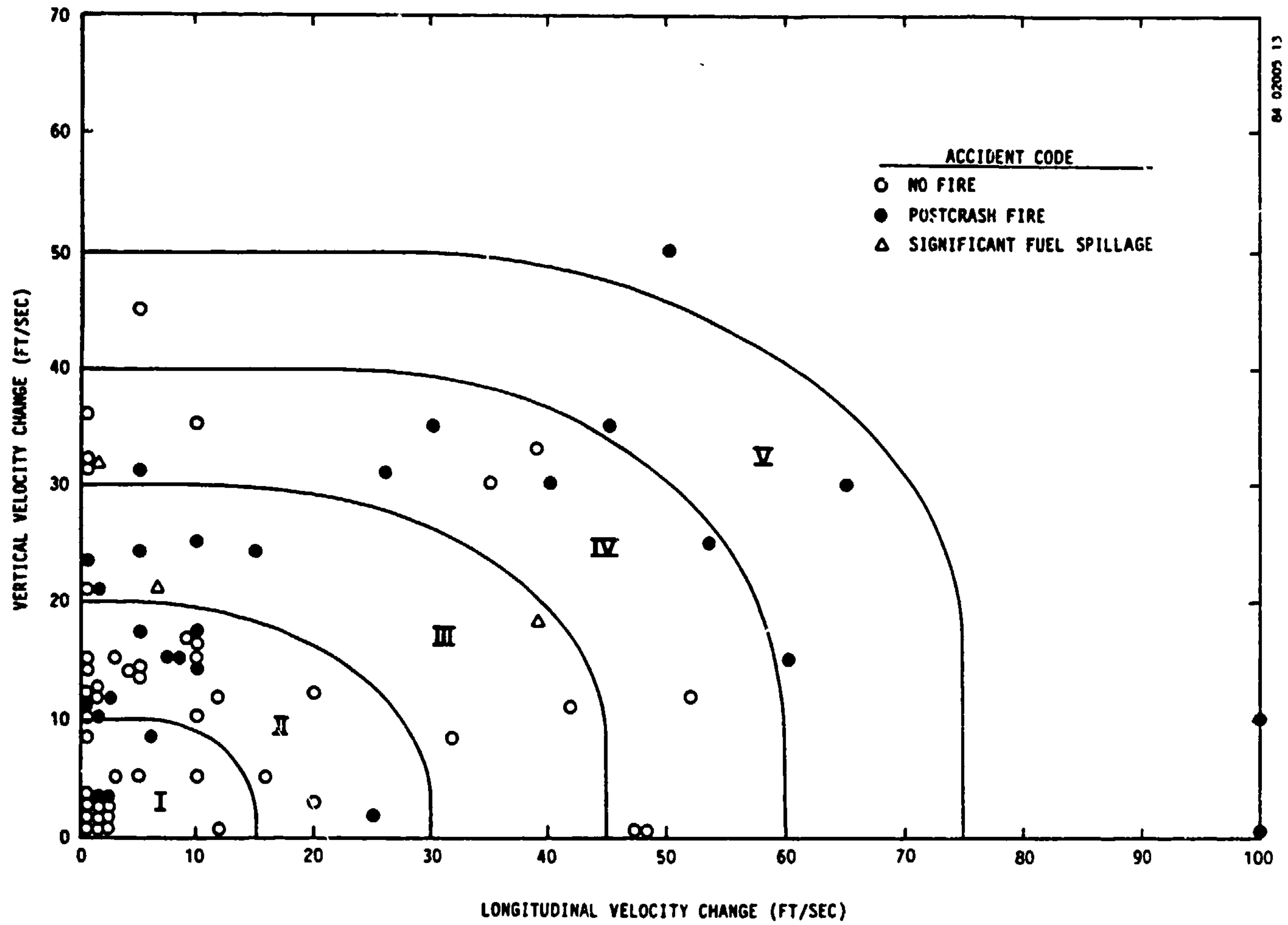


Figure 23. Incidence of Postcrash Fire According to Impact Velocity for Survivable Land Impacts.

Table 17. Incidence of Postcrash Fire According to Accident Severity Level for Land Accidents

Accident Severity Level	Number of Land Accidents	Number of Accidents with Postcrash Fire	Percentage of Accidents with Postcrash Fire (%)
I	20	4	20.0
II	25	8	32.0
III	10	5	50.0
IV	15	5	33.3
V	4	3	75.0

Table 18. Total Injury Costs According to Accident Severity Level

Accident Severity Level	Number of Major Injuries and Fatalities in Survivable Accidents	Injury Cost in Survivable Accidents ($)	Percentage of Total Injury Cost in Survivable Accidents
I	23	232,130	0.9
II	26	1,961,670	7.8
III	49	4,727,075	18.9
IV	99	9,489,790	37.9
V	36	5,543,840	22.1
Other or Unknown	61	3,102,011	12.4
TOTAL	294	25,056,516	100.0
INJURY COST IN NONSURVIVABLE ACCIDENTS		23,851,000	
TOTAL INJURY COSTS		48,907,516	

PART II: MARITIME AIRCRAFT

MARITIME AIRCRAFT ACCIDENT SAMPLE

The accident sample consisted of all flight mishaps (71) of Navy maritime aircraft not equipped with ejection seats which occurred during the calendar years 1972 to 1981. Table 19 shows the breakdown according to aircraft type and basic mission classification. Three major series of aircraft were considered in this study: land based, carrier capable, and trainer. Fourteen different aircraft models were examined in the study.

ACCIDENT STATISTICS

The accidents for the three major aircraft series were classified according to three levels of accident severity: low severity, significant survivable, and nonsurvivable (definitions for these classifications can be found at the beginning of the report). Table 20 shows the distribution of accidents according to severity and occurrence on land and water. The key accidents considered in this study were the 8 significant survivable water accidents and 15 significant survivable land accidents. Note that all 71 accidents had to be reconstructed in order to make the determination of accident severity. However, a greater percentage of time was spent in analyzing the impact conditions and injuries in the significant accidents. Table 21 shows a comparison between actual accidents on water and ditchings classified as flight mishaps due to aircraft damage. For example, the carrier capable aircraft had a total of 16 flight mishaps occurring during the evaluation period. Seven of these mishaps were water related and significant enough to be classified as accidents. Only one aircraft was subsequently lost due to lack of flotation or bouyancy. The greatest percentage of aircraft losses in water related mishaps were the result of significant crash forces at the time of impact.

All of the aircraft series had mishaps occurring both on land and water; however, the trainers had predominately land mishaps due to the basic mission requirements. Figure 24 presents the relative percentage of mishaps occurring on land and water for each type of aircraft. The land based and carrier capable series were almost evenly divided between water and land mishaps.

The number of persons receiving major and fatal injuries in maritime aircraft accidents was greatly influenced by the number of land impacts. A total of 164 out of 249, or 65 percent, of the major injuries and fatalities occurred in land impacts. Figure 25 presents the number of persons receiving these serious injuries for each aircraft series.

TERRAIN

Terrain at the impact site was tabulated from the flight surgeon's report (Table 22). The following trends can be seen in the terrain data for the combined sample:

- 25.4 percent occurred on water
- 49.2 percent occurred on flat ground
- 25.4 percent occurred in or through trees, or onto uneven ground.

Table 19. Summary of Maritime Aircraft Flight Mishaps, 1972-1981, by Model

Aircraft Type	Model	No. of Mishaps*	Aircraft Type	Model	No. of Mishaps*
Land Based	Lockheed		Carrier	Grumman	
	P-2	1	Capable	C-1	3
	P-3	9		C-2	1
				S-2	6
	Grumman			E-1	1
	C-4	1		E-2	5
					16
	Douglas				
	C-117	2			
	C-118	2	Trainers	North American Rockwell	
	Lockheed			T-28	22
	C-130	1			
				Beech	
	Convair			T-34	16
	C-131	1			38
		17			

* Total maritime aircraft mishaps: 71

Table 20. Maritime Aircraft Flight Mishaps Categorized by Aircraft Type and Accident Severity

Aircraft Type	Water Mishaps			Land Mishaps			Total
	Low Severity	Significant Survivability	Nonsurvivable	Low Severity	Significant Survivable	Nonsurvivable	
Land Based	1	3	3	1	2	7	17
Carrier Capable	1	3	3	1	2	6	16
Trainers	2	2	1	11	11	11	38
Total	4	8	7	13	15	24	71

Table 21. Water-Related Accidents and Ditchings in Maritime Aircraft Flight Mishaps, 1972-1981

Aircraft Type	Total No. of Mishaps	No. of Water-Related Accidents	Total No. of Ditchings	No. of Aircraft Lost
Land Based	17	7	0	0
Carrier Capable	16	7	0	1
Trainers	38	5	0	0
Total	71	19	0	1

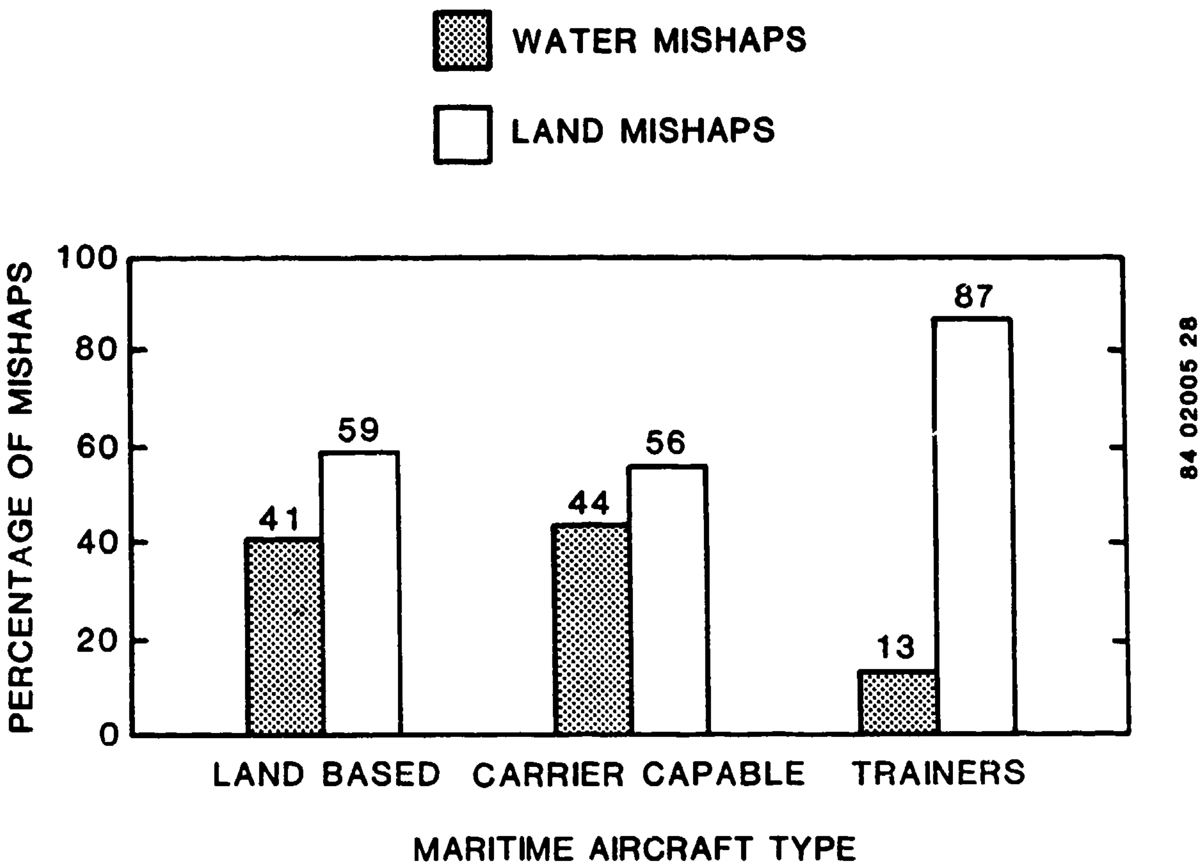


Figure 24. Distribution of Flight Mishaps According to Maritime Aircraft Type.

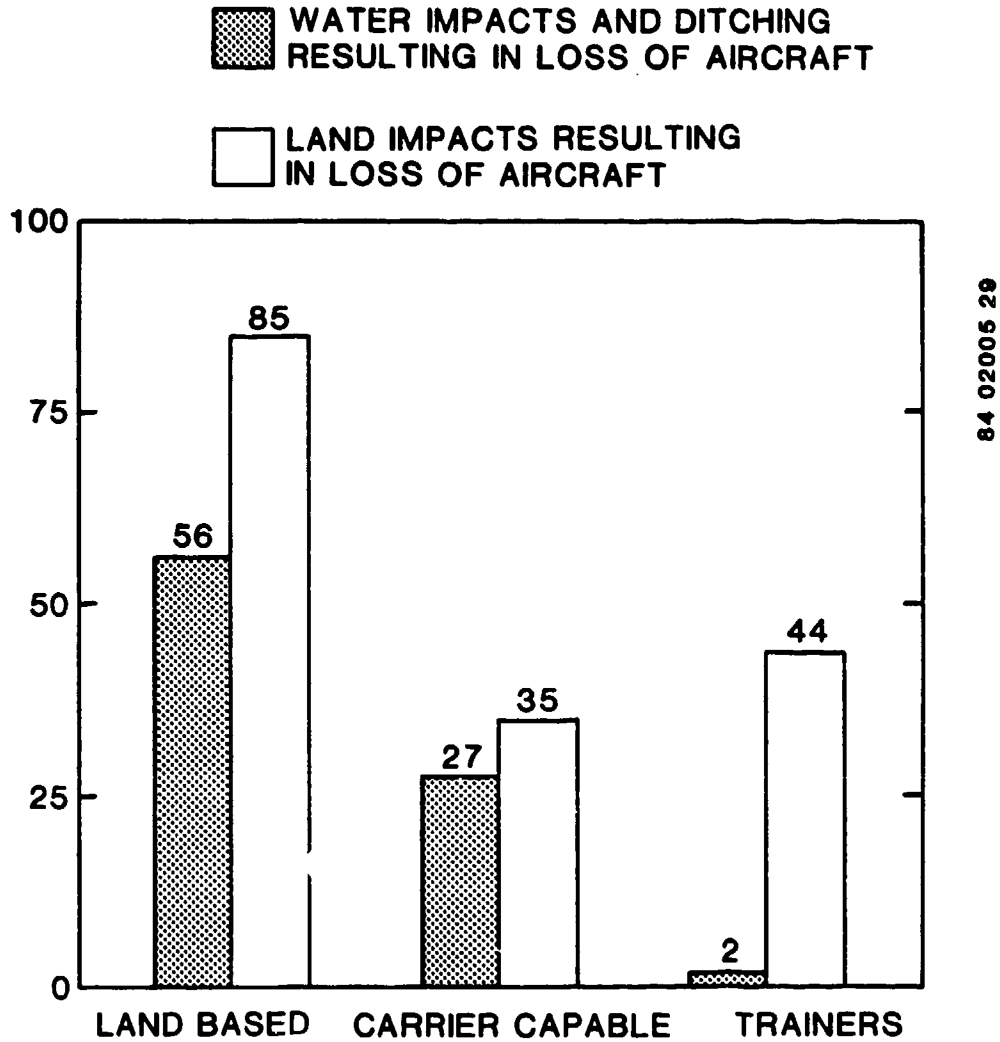


Figure 25. Number of Persons Receiving Major and Fatal Injuries in Maritime Aircraft Flight Mishaps.

Table 22. Terrain at Impact Site as Classified in Flight Surgeon's Report

	No. of Occurrences by Maritime Aircraft Type			
Classification	Land Based	Carrier Based	Trainers	Total
Open Sea	5	6	1	12
River				
Deep Water	2		3	5
Shallow Water		1		1
Deep Snow	1			1
Marsh/Swamp/Mud				
Soft Ground	3	3	13	19
Dense Woods	1	1	2	4
In Trees				
Through Trees	1		8	9
Ravine/Steep Slope	3	2		5
Rocks				
Desert			2	2
Hard Ground	1	3	9	13
Runway				
Flight Deck				
Total	17	16	38	71

MARITIME AIRCRAFT IMPACT PARAMETERS

Impact parameters were estimated during the accident evaluation effort from the aircraft orientation and velocity at the instant before the principal impact. Estimates of orientation and velocity were based on occupant and witness statements, the mission, aircraft performance characteristics, and structural damage at impact. It was not always possible to make a determination of orientation and velocity for every accident case; however, there was a sufficient number of accidents with estimated impact parameters to develop a statistical description of the accident environment.

ORIENTATION AT IMPACT

The distribution of impact angles was based on 23 significant survivable accidents with at least one known angle. Pitch, roll, and yaw angles are defined as angular deviations about the three mutually perpendicular aircraft axes, as illustrated in Figure 26. The impact angle is defined as the angle between the flight path velocity vector and the impacted surface.

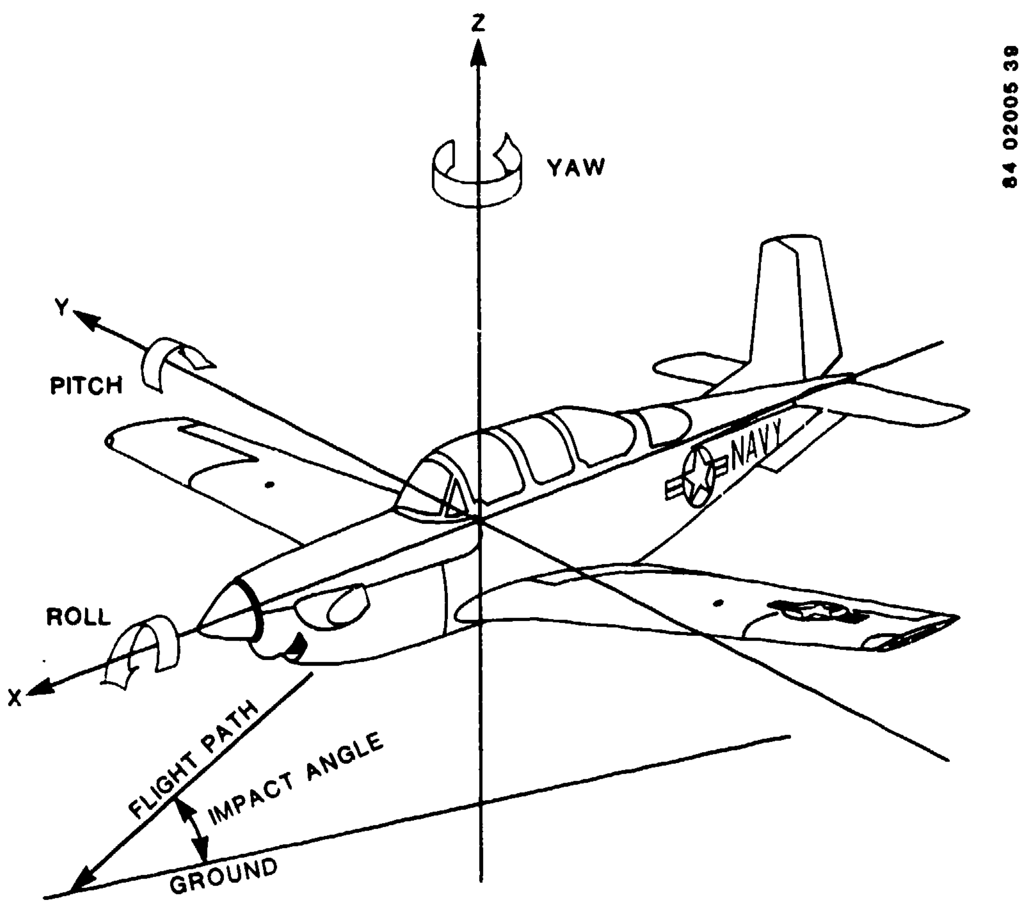


Figure 26. Aircraft Coordinate and Attitude Directions.

Pitch Angle

The distribution of pitch angle magnitude and direction is listed in Table 23. Approximately 90 percent of the impacts occurred between -10 and +10 degrees pitch, and 100 percent occurred between ±20 degrees. Thirty-five percent of the impacts occurred with upward, or positive, pitch and 20.0 percent with downward, or negative, pitch angle.

Table 23. Distribution of Pitch Angle and Direction at Impact for Survivable Maritime Aircraft Accidents on Land and Water

Angle (Deg)	No. of Accidents per Direction Up	Level	Down	Total Accidents	Percent of Accidents (%)	Cumulative Percent (%)
0		9		9	45.0	45.0
1-10	7		2	9	45.0	90.0
11-20	0		2	2	10.0	100.0
21-30	0		0	0	0.0	
31-45	0		0	0	0.0	
46-60	0		0	0	0.0	
61-75	0		0	0	0.0	
76-90	0		0	0	0.0	
91-120	0		0	0	0.0	
121-150	0		0	0	0.0	
151-180	0		0	0	0.0	
Total				20	100.0	
Unknown				3		

Roll Angle

The distribution of roll angle at impact is listed in Table 24. Eighty percent of the impacts occurred between -10 and +10 degrees roll, while the remaining were distributed between ±10 and ±180 degrees.

Table 24. Distribution of Roll Angle and Direction at Impact for Survivable Maritime Aircraft Accidents on Land and Water

Angle (Deg)	No. of Accidents per Direction: Left	Level	Right	Total Accidents	Percent of Accidents (%)	Cumulative Percent (%)
0		14		14	70.0	70.0
1-10	1		1	2	10.0	80.0
11-20	0		0	0	0.0	80.0
21-30	0		1	1	5.0	85.0
31-45	0		0	0	0	85.0
46-60	0		1	1	5.0	90.0
61-75	0		1	1	5.0	95.0
76-90	0		0	0	0	95.0
91-120	0		0	0	0	95.0
121-150	0		0	0	0	95.0
151-180	1		0	1	5.0	100.0
Total				20	100.0	
Unknown				3		

Yaw Angle

The distribution of yaw angle at impact is listed in Table 25. Ninety-five percent of the survivable accidents occurred at approximately zero degrees yaw. This distribution indicates that yaw is not a significant factor in survivable maritime aircraft accidents.

Table 25. Distribution of Yaw Angle and Direction at Impact for Survivable Maritime Aircraft Accidents on Land and Water

Angle (deg)	No. of Accidents per Direction: Left	Level	Right	Total Accidents	Percent of Accidents (%)	Cumulative Percent (%)
0		19		19	95.0	95.0
1-10	0		1	1	5.0	100.0
11-20						
21-30						
31-45						
46-60						
61-75						
76-90						
91-120						
121-150						
151-180						
Total				20	100.0	
Unknown				3		

Impact Angle

The distribution of impact angle is listed in Table 26. Approximately 85 percent of the survivable accidents occurred between 0 and 10 degrees. This impact angle distribution indicates that the velocity vector at impact was primarily longitudinal and that the occurrence of survivable accidents with both high longitudinal and high vertical forces was relatively rare.

Table 26. Distribution of Impact Angle for Survivable Maritime Aircraft Accidents on Land and Water

Angle (deg)	Total Number	Percent of Total (%)	Cumulative Percent (%)
0	6	30.0	30.0
1-10	11	55.0	85.0
11-20	1	5.0	90.0
21-30	1	5.0	95.0
31-45	1	5.0	100.0
46-60	0	0	
61-75	0	0	
76-90	0	0	
Total	20	100.0	
Unknown	3		

IMPACT VELOCITY CHANGE

The distribution of impact velocity change is based on the 23 significant survivable accidents used to define the impact angles. Cumulative frequency curves are presented in this section for impacts on both land and water combined. The 95th-percentile velocity change level is also shown for each curve. There were not sufficient data to warrant the determination of separate distribution curves for land and water impacts. The Reference 1 study (flight mishaps during 1969 to 1971) did not tabulate velocity changes for this type of aircraft; thus, there is no basis for comparison of the current data.

Longitudinal Velocity Change

Figure 27 shows the cumulative frequency distribution for the longitudinal velocity change on land and water. The 95th-percentile survivable longitudinal impact velocity change was 88 ft/sec for land and water impacts. Of the 23 significant survivable maritime aircraft accidents, longitudinal velocity could be estimated in just 14 cases--a relatively small number on which to base the 95th-percentile survivable accident condition.

Vertical Velocity Change

The vertical velocity change curves for land and water impacts are shown in Figure 28. The 95th-percentile survivable vertical velocity change component was found to be 38 ft/sec for land and water accidents. It is interesting to note that the 95th-percentile survivable velocity change for maritime aircraft (38 ft/sec) was very similar to that found for helicopters (38 ft/sec for land impacts and 39 ft/sec for water impacts).

These data indicate that the human body is very sensitive to vertical velocity change and that there is a threshold tolerance level above which serious injury would be expected to occur. The comparable vertical velocity change levels found for fixed-wing aircraft and helicopters supports this finding.

Lateral Velocity Change

There were not sufficient data tabulated to support calculation of a lateral velocity change distribution for maritime aircraft. However, in those cases in which it was tabluated the lateral velocity change values were less than 5 ft/sec. Thus, lateral velocity change does not appear to be as significant a factor for fixed-wing aircraft as for helicopters.

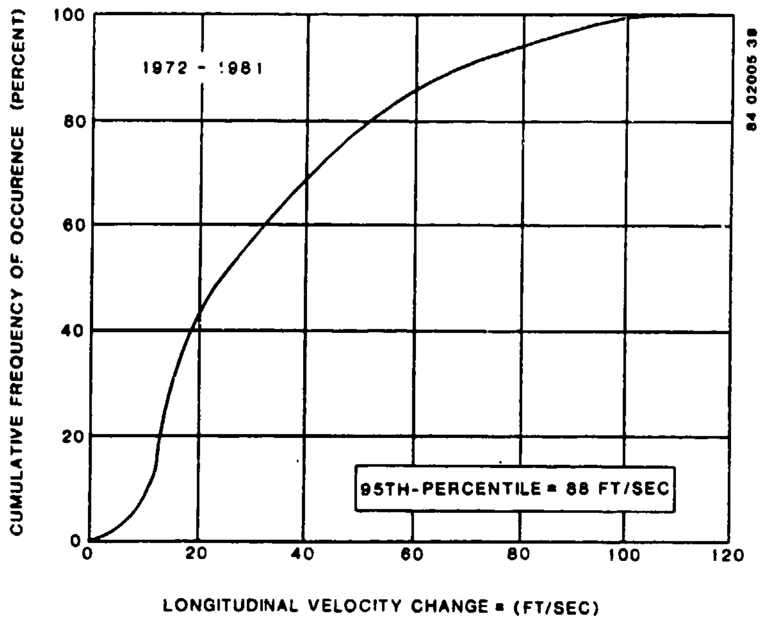


Figure 27. Cumulative Frequency Curve for Longitudinal Velocity Change in Survivable Land and Water Accidents.

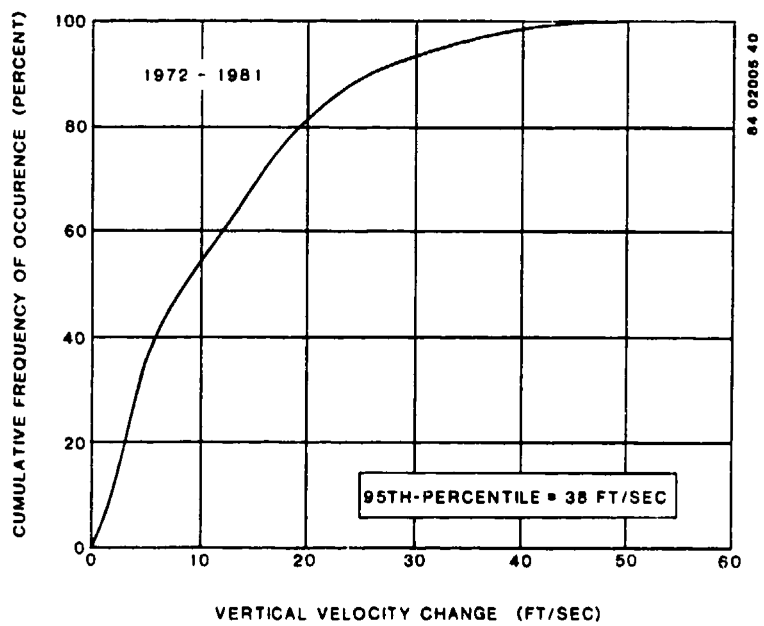


Figure 28. Cumulative Frequency Curve for Vertical Velocity Change in Survivable Land and Water Accidents.

MARITIME AIRCRAFT INJURY/HAZARD ANALYSIS

This section contains a summary of the number of injuries and injury rates in each of the aircraft series. As noted previously, an attempt was made during the accident reconstruction to correlate a hazard with each injury. Tables are presented in this section with a ranking of these hazards according to estimated total costs for the 10-year study period. These hazards indicate several potential areas for improved crashworthiness in maritime aircraft.

INJURY RATES

Major and fatal injuries were tabulated for each accident review. For the entire sample of 71 flight mishaps of all severities, there were 219 major and fatal injuries. Figure 29 shows the number of injuries according to aircraft type. By far, the land based aircraft (P-3, C-118, C-1, C-130, C-4, C-131 and C-117) accounted for the greatest number of severe injuries. The highest injury total occurred in the P-3, accounting for 69 of the 219 major and fatal injuries.

Major and fatal injuries were also tabulated for the 23 significant survivable accidents examined. It was found that only 59, or approximately 27 percent, of the total 219 major injuries and fatalities occurred in the significant survivable accidents. The remaining 73 percent of these injuries occurred in nonsurvivable accidents. Figure 30 shows the distribution of major injuries and fatalities in the survivable accident group.

OCCUPANT INJURY PATTERNS

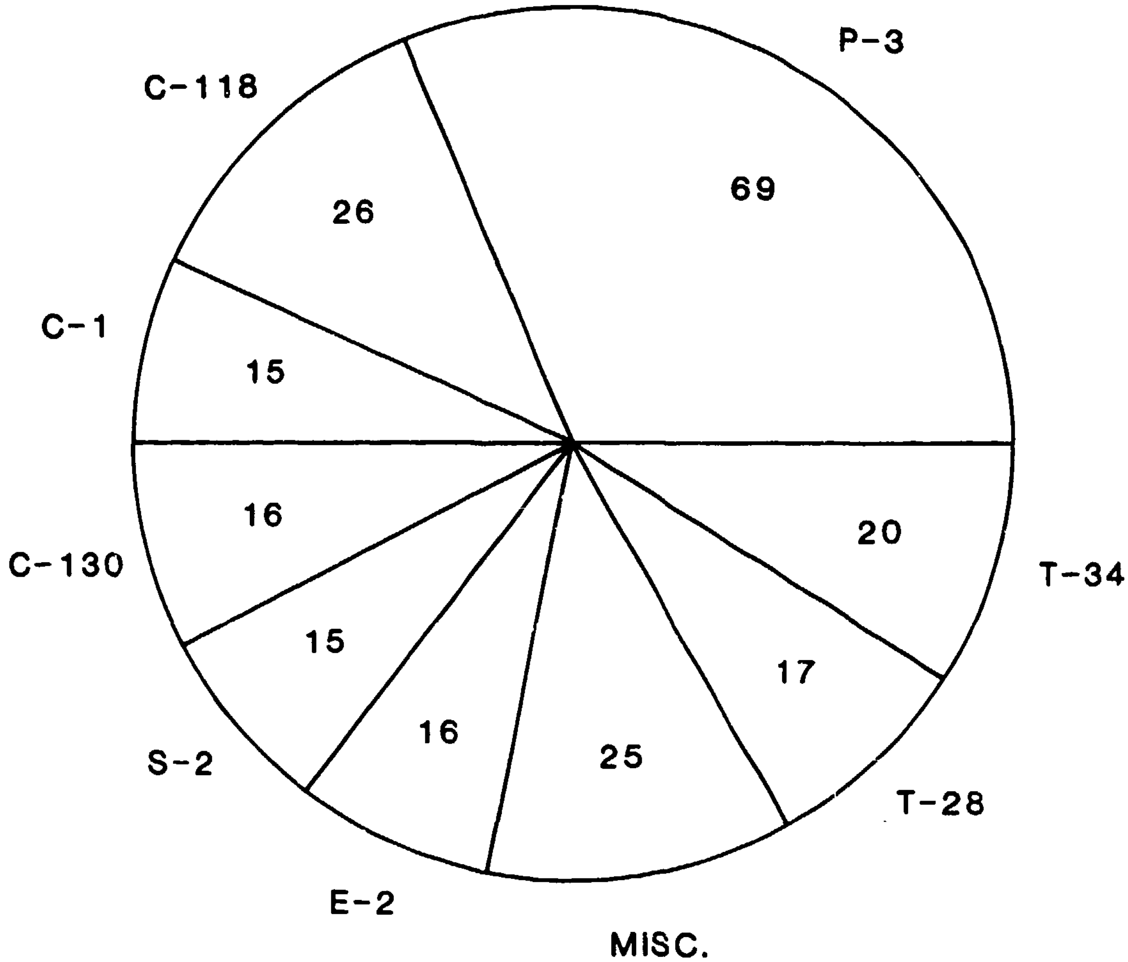
Injuries were compiled from all survivable accidents and included all impact-related injuries except burns, drowning, and multiple extreme injuries. The injuries were categorized into seven body areas: head, neck, legs, arms, back, chest, and abdomen. A percentage of occurrence was calculated based on the total number of injuries recorded. The results can be seen in Figures 31 through 34, which show the injury patterns for each aircraft grouping (i.e., land based, carrier capable, or trainer) as well as all maritime aircraft combined. The combined results show the head, neck, legs, and arms are most susceptible to injury, indicating the high percentage of secondary impact injuries. These injuries result from impact on surrounding structure due to flailing, poor (or lack of) restraint, and failure of seats to sustain the crash loads. The other major trend found in the data is the predominance of spinal injuries in land based aircraft (see Figure 31), which accounted for almost half the injuries recorded.

HAZARD ANALYSIS

The same hazard analysis technique used for the helicopter flight mishaps (adapted from Reference 8) was used to evaluate hazards in the maritime aircraft. The methodology used in this technique is to tabulate the following four items:

1. Medical description of the trauma
2. Mechanism by which the trauma occurred
3. Underlying hazard which caused the trauma
4. Resulting cost.

TOTAL NUMBER OF PERSONS RECEIVING
MAJOR AND FATAL INJURIES = 219



84 02005 41

MISC. = C-4, C-131, C-117, C-2

Figure 29. Total Number of Persons Receiving Major and Fatal Injuries in Maritime Aircraft Flight Mishaps of all Severities (Survivable and Nonsurvivable).

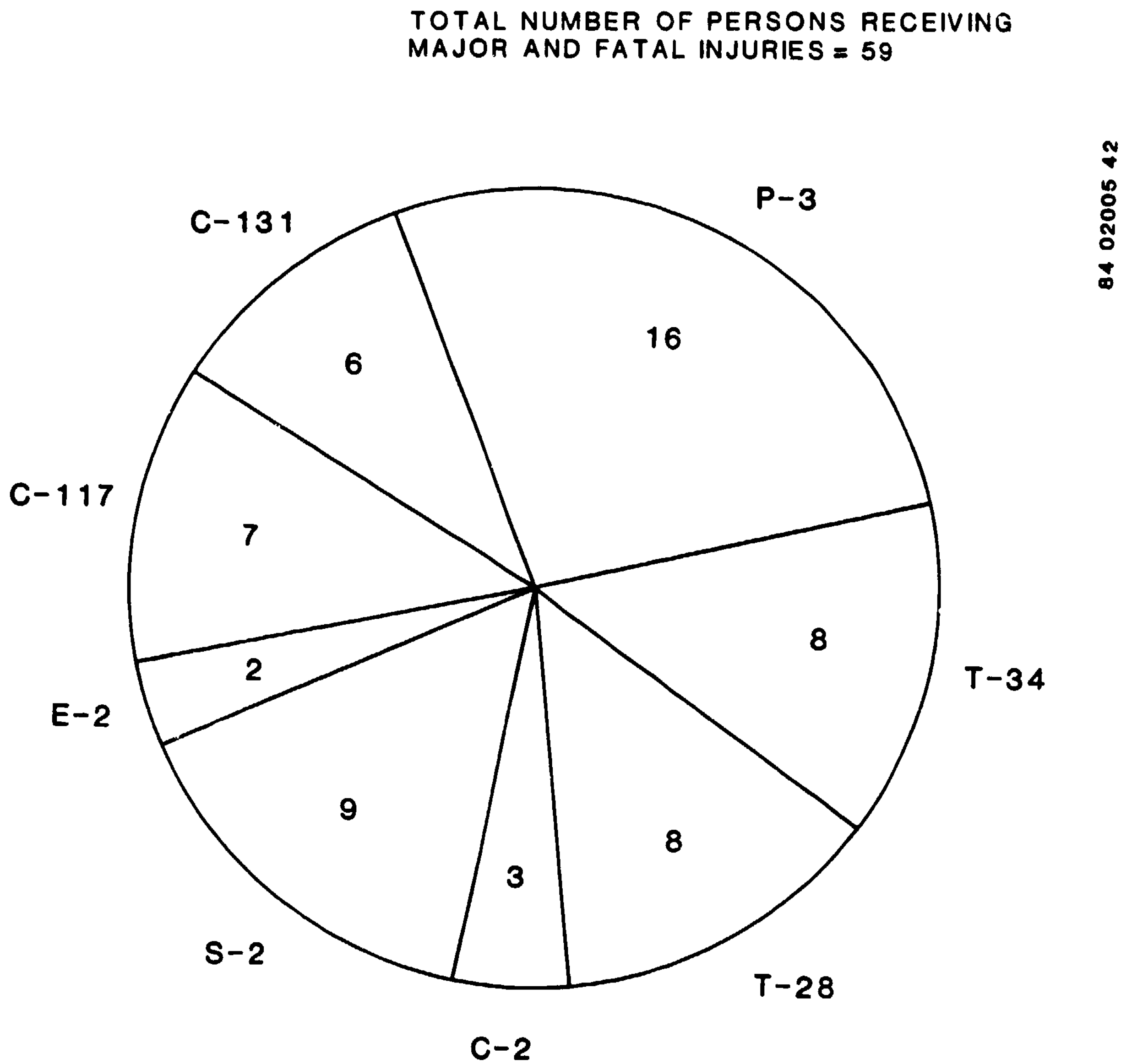


Figure 30. Total Number of Persons Receiving Major and Fatal Injuries in Survivable Maritime Aircraft Flight Mishaps.

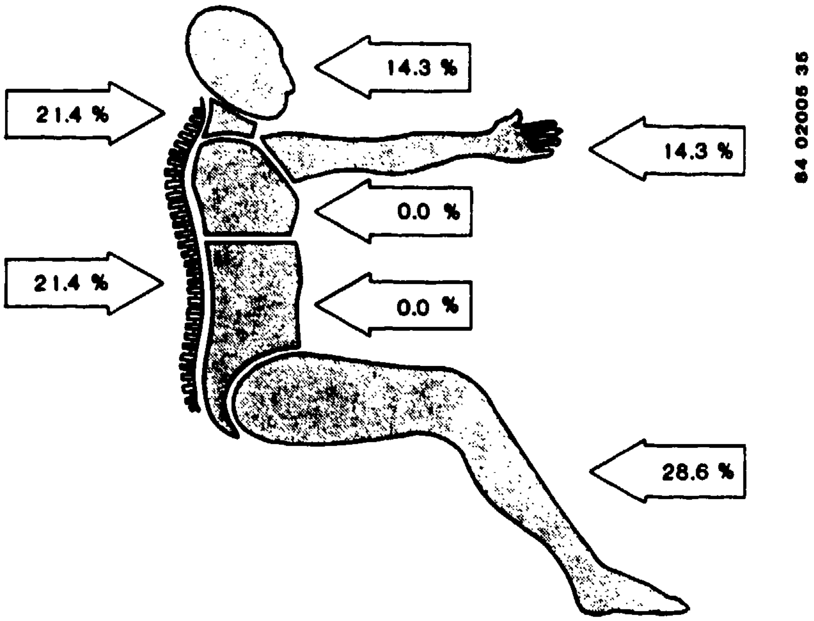


Figure 31. Injury Pattern for Land Based Maritime Aircraft Occupants (Based on 14 Recorded Injuries).

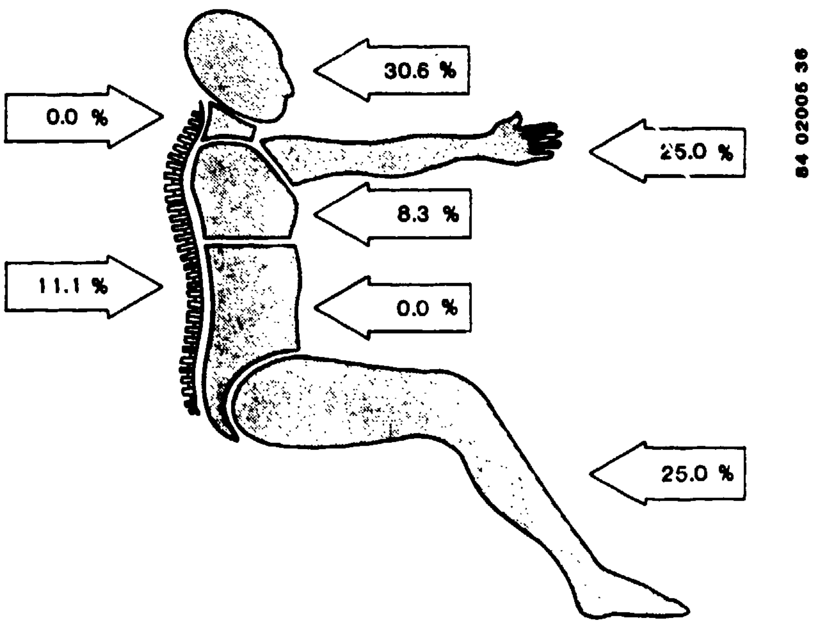


Figure 32. Injury Pattern for Carrier Capable Maritime Aircraft Occupants (Based on 36 Recorded Injuries).

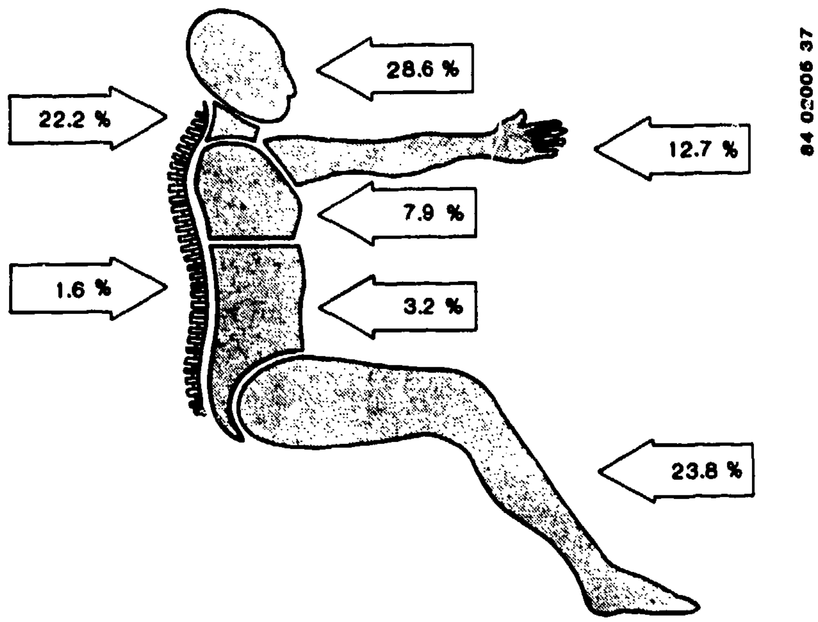


Figure 33. Injury Pattern for Maritime Training Aircraft Occupants (Based on 63 Recorded Injuries).

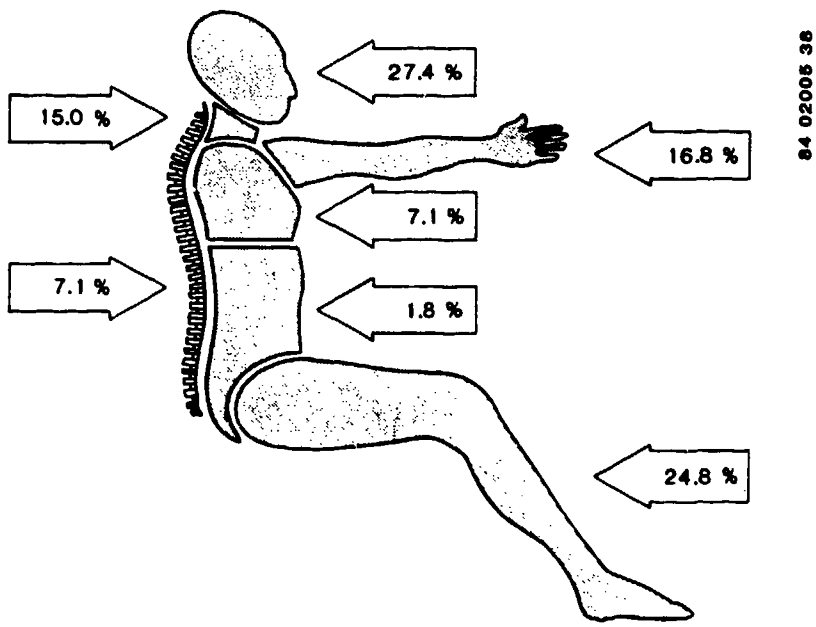


Figure 34. Injury Pattern for all Maritime Aircraft Occupants (Based on 113 Recorded Injuries).

Injury cost data were based on the values listed in OPNAV Instruction P3750.6N (Reference 4). The costs for Alfa, Bravo and Charlie injuries are taken directly from Table A-1, Appendix A, which is a reproduction of the cost table from OPNAV Instruction P3750.6N. The injury costs for Delta, Echo, and Foxtrot injuries were based on costs for days hospitalized and lost work-days, using the equation for number of days as shown in Table 10.

Sixteen specific hazards were identified as causes of injuries in this study and are ranked in Table 27 according to the total cost of injuries produced in all models. The total cost of injuries in survivable accidents was estimated to be $7.7 million. Approximately 20 percent of this amount, $1.5 million, was attributable to seat structural failures allowing the occupant to impact aircraft structure. The second most prevalent hazard was found to be due to postcrash fires causing thermal injuries, which accounted for $1.4 million of the total injury cost. An additional $32.8 million worth of injury costs were accrued in accidents considered to be nonsurvivable. The total cost of all injuries (in survivable and nonsurvivable accidents) during the 10-year period was $40.5 million.

The number of major or fatal injuries attributable to the 16 hazards are listed in Table 28. Fifty-nine persons received a total of 75 injuries of these severities in survivable accidents, all due to causes presented in this study. Because of the highly nonlinear relationship between injury cost and injury severity, the total number of major injuries and fatalities for each hazard (shown in the last column of Table 28) does not have the same descending progression as the total cost in Table 25. With this in mind, Table 29 was developed to summarize and prioritize the potential areas for improved crashworthiness in U.S. Navy maritime aircraft.

The most serious crash hazard resulted from failure of the structural integrity of crew and troop seats. This problem was noted repeatedly in accident reports as an inherent problem in several of these aircraft models.

The second most significant hazard relates to restraint systems, particularly poor utilization of existing equipment and the lack of crash restraint provided by passenger belts. These problems were most common in the large capacity land based maritime aircraft. Failure to utilize existing restraints was almost entirely limited to passengers and crewmembers performing duties in the aft sections of the aircraft.

The third most serious hazard was the failure of fuel systems, resulting in postcrash fire, which occurred in all three categories of aircraft. The incidence of postcrash fires in land and water mishaps is shown in Table 30. As might be expected, there were no postcrash fires in water impacts. Also, the relatively low percentage of mishaps with postcrash fire for maritime aircraft (15.8 percent) versus Navy and Marine helicopters (41.2 percent) was an important finding. Table 31 compares the number of injuries and fatalities caused by fires (thermal) and all other causes (nonthermal). Approximately 11 percent of the injuries and fatalities in maritime aircraft were fire related. The number of injuries and fatalities caused by fires is relatively low.

The fourth most serious problem was the aircraft structure entering occupied areas of the fuselage, a problem that cannot be easily corrected since enhancing the structural integrity of the fuselage will have a significant weight and cost penalty. The only specific recommendation that can be made is to incorporate a system design approach to crashworthiness in future aircraft specifications to insure that the maximum level of crashworthiness can be achieved.

The final crash hazard was due to postcrash egress problems in which occupants were unable to egress the aircraft in adequate time to escape the aircraft fire or injured occupants could not be rescued due to submerging of the aircraft.

Table 27. Injury Costs Attributable to 16 Hazards in Survivable Maritime Aircraft Accidents

Hazard No.	Hazard Description	Injury Costs in Survivable Accidents - by Maritime Aircraft Series (in Thousands of Dollars) Land Based	Carrier Capable	Trainers	Total Injury Cost for Hazard ($)
1	Body struck aircraft structure when seat failed	874,390	667,635	1,517	1,543,542
2	Body exposed to fire when fuel system failed on impact	1,054,000		90,621	1,144,621
3	Body struck aircraft structure when structure collapsed excessively	3,565	676,430	410,000	1,089,995
4	Body injured during postcrash egress	658,205	7,725		665,930
5	Body drowned due to unknown causes	204,000		330,000	534,000
6	Body struck aircraft structure when seats failed due to intrusion of landing gear		479,035		479,035
7	Upper body struck structure because restraint was not used properly		435,902	3,035	438,937
8	Upper body struck structure because restraint allowed excessive motion	330,000			330,000
9	Body struck aircraft structure while not restrained during impact	294,385			294,385

Table 27 (Contd). Injury Costs Attributable to 16 Hazards in Survivable Maritime Aircraft Accidents

Hazard No.	Hazard Description	Injury Costs in Survivable Accidents - by Maritime Aircraft Series (in Thousands of Dollars) Land Based	Carrier Capable	Trainers	Total Injury Cost for Hazard ($)
10	Body received excessive decelerative force when aircraft and seat allowed excessive loading	86,030	121,517	5,782	213,329
11	Body struck aircraft structure when restraint failed	82,315			82,315
12	Body struck by loose internal object	3,675	40,000		43,675
13	Body injured due to contact forces of restraint system			12,139	12,139
14	Body struck by inrushing water		6,070		6,070
15	Body struck equipment within the strike envelope		805	1,812	2,617
16	Body received excessive inertial force due to improper use of restraint			2,385	2,385
17	All other injury causes (missing aircraft, unknown or unclassified injuries, and injuries suffered during rescue)	50,770	952,000	376,035	1,378,805
TOTAL INJURY COST IN SURVIVABLE ACCIDENTS					7,715,859
TOTAL INJURY COST IN NONSURVIVABLE ACCIDENTS					32,805,000
TOTAL INJURY COST					40,520,859

Table 28. Number of Major Injuries and Fatalities Attributable to 16 Hazards in Survivable Maritime Aircraft Accidents

Hazard No.	Hazard Description	Injury Costs in Survivable Accidents - by Maritime Aircraft Series (in Thousands of Dollars) Land Based	Carrier Capable	Trainers	Total Injury Cost for Hazard ($)
1	Body struck aircraft structure when seat failed	11	8	1	20
2	Body exposed to fire when fuel system failed on impact	5	0	4	9
3	Body struck aircraft structure when structure collapsed excessively	0	3	2	5
4	Body injured during postcrash egress	8	2	0	10
5	Body drowned due to unknown causes	1	0	1	2
6	Body struck aircraft structure when seats failed due to intrusion of landing gear	0	2	0	2
7	Upper body struck structure because restraint was not used properly	0	3	1	4
8	Upper body struck structure because restraint allowed excessive motion	1	0	0	1
9	Body struck aircraft structure while not restrained during impact	3	0	0	3

Table 28 (Contd). Number of Major Injuries and Fatalities Attributable to 16 Hazards in Survivable Maritime Aircraft Accidents

Hazard No.	Hazard Description	Injury Costs in Survivable Accidents - by Maritime Aircraft Series (in Thousands of Dollars) Land Based	Carrier Capable	Trainers	Total Injury Cost for Hazard ($)
10	Body received excessive decelerative force when aircraft and seat allowed excessive loading	2	2	1	5
11	Body struck aircraft structure when restraint failed	2	0	0	2
12	Body struck by loose internal object	1	0	0	1
13	Body injured due to contact forces of restraint system	0	0	1	1
14	Body struck by inrushing water	0	2	0	2
15	Body struck equipment within the strike envelope	0	0	0	0
16	Body received excessive inertial force due to improper use of restraint	0	0	0	0
17	All other injury causes (missing aircraft, unknown or unclassified injuries, and injuries suffered during rescue)	1	4	3	8
TOTAL		35	26	14	75

Table 29. Summary of Potential Areas for Improved Crashworthiness in Maritime Aircraft

Priority	Potential Areas for Improvement	Hazards Resulting	Number of Major Injuries and Fatalities in Survivable Accidents	Total 10-year Injury Cost in Survivable Accidents ($)	Predominate Models and Percentage of Total 10-year Injury Cost
1	Crew and troop seats separate from aircraft and/or transmit intolerable vertical loads to occupants	1, 6, 10	27	2,235,906	C-2 (30%) E-2 (21%) P-3 (11%)
2	Poor utilization of existing restraints and/or failure of the system to provide effective restraint which allows secondary impacts	7, 8, 9, 11, 13, 16	11	1,160,161	S-2 (38%) C-117 (16%) C-131 (16%)
3	Fuel systems fail on impact resulting in postcrash fire with subsequent thermal injuries to occupants	2	9	1,144,621	C-131 (91%)* T-28 (7%)
4	Failure of fuselage during impact allows structure to enter occupied areas	3, 14	7	1,096,065	C-2 (62%) T-34 (37%)
5	Postcrash egress problems resulted in injury or death	4	10	665,930	P-3 (99%)

* Due to one major accident, results not considered significant for model shown.

Table 30. Postcrash Fire Experience in Maritime Aircraft Survivable Accidents

Category	Land Impacts			Water Impacts		
	No. of Mishaps	No. of Fires	Percentage of Fires (%)	No. of Mishaps	No. of Fires	Percentage of Fires (%)
Land Based	7	1	14.3	0	0	0
Carrier Capable	8	1	12.5	0	0	0
Trainers	23	4	17.4	0	0	0
Total	38	6	15.8	0	0	0

Table 31. Comparison of Thermal and Nonthermal Injuries and Fatalities in Survivable Land Impacts

Category	Injuries		Fatalities		Percent Injuries/Fatalities Caused by Fire (%)
	Thermal	Nonthermal	Thermal	Nonthermal	
Land Based	1	35	4	12	9.6
Carrier Capable	1	11	0	14	3.8
Trainers	6	20	0	2	21.4
Total	8	66	4	28	11.3

PART III: CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The cost of injuries and associated loss of readiness is a serious problem in Navy and Marine helicopters and maritime aircraft. The number of fatalities in aircraft with fixed seating systems significantly exceeds those due to ejection in high-performance Naval aircraft. It was found that almost 76 percent of the fatalities and major injuries in helicopters occurred in survivable accidents; that is, those in which the accelerations do not exceed human tolerance and the airframe retains livable volume during the impact. The cost of these injuries in survivable helicopter accidents was estimated to total $25.1 million in 1982 dollars. When the cost of injuries from accidents considered to be nonsurvivable in the older generation of helicopters is added, the total injury cost becomes approximately $48.9 million. Thus, the magnitude of injury cost and the fact that the injuries occur in "survivable" accidents indicates the need for further examination and research.

Conversely, almost 73 percent of the major injuries and fatalities that occurred in maritime aircraft flight mishaps were associated with nonsurvivable accidents. The cost of injuries in these nonsurvivable accidents was estimated at $32.8 million compared to $7.7 million for injuries in survivable accidents.

A hazard analysis conducted revealed the following six major causes of injuries and fatalities in survivable accidents which were common to both helicopters and maritime aircraft:

1. Failure of seats, especially crewseats, to retain the occupants and limit vertical forces to prevent spinal injury.

2. Failure of fuel systems during impact, resulting in thermal injuries.

3. Poor utilization of existing restraints, especially by passengers, and use of the gunner's belt as the primary restraint device in helicopters, which in both cases permits secondary impact.

4. Inability to egress the aircraft during fire or submersion in water.

5. Displacement of main rotor blades into occupied space (helicopters only).

6. Failure of fuselage structure permitting intrusion of external objects, or structural collapse resulting in secondary impact injuries.

The problems associated with crewseats were, by far, the greatest hazard in both types of aircraft examined. Several retrofit and improvement programs are currently underway which are expected to help to reduce this hazard.

Although not specifically tabulated in this study, training and flight equipment played an extremely important role in survival and minimization of injury. Aircrewmembers repeatedly credited emergency underwater egress training with their ability to exit sinking aircraft (often inverted). A subjective assessment is that the survival rate for passengers without the benefit of this training was significantly lower.

Helmets for aircrew and cranial protectors for passengers were very effective at reducing the number and severity of incapacitating head injuries. Nomex flight suits played an important role in reducing the number and severity of burn injuries. Without this training and equipment, the total cost of injuries would have been many times greater.

A significant portion of this study was associated with reconstructing the impact kinematics of flight mishaps to develop a statistical summary of crash impact conditions. Of the parameters tabulated, the velocity change during principal impact has the greatest influence on survivability. It was found that 95 percent of all survivable helicopter accidents had velocity change components less than or equal to:

- 55 ft/sec on land and 72 ft/sec on water in the longitudinal direction
- 38 ft/sec on land and 39 ft/sec on water in the vertical direction
- 29 ft/sec on land and 42 ft/sec on water in the lateral direction.

The 95th-percentile velocity change components for land impacts compare favorably with those contained in MIL-STD-1290(AV) and the U.S. Army Aircraft Crash Survival Design Guide. These documents represent the current state of the art in crashworthiness design for helicopters and light fixed-wing aircraft. It should be noted that a significant number of major injuries and fatalities occurred at or below these velocity change levels. This finding indicates that the airframes are capable of providing a survivable container at these velocity levels; however, seats, restraints, and other components in these older aircraft were not designed to withstand the full force levels. To improve this situation, current retrofit programs are addressing the need for seats and restraints capable of sustaining higher loads under dynamic loading conditions.

Analysis of crash conditions for the maritime aircraft accident sample indicates that 95 percent of the survivable accidents have velocity change components less than or equal to:

- 88 ft/sec on land and water combined in the longitudinal direction
- 38 ft/sec on land and water combined in the vertical direction.

Since there is not a current specification governing crashworthiness of the maritime aircraft, the velocity change values identified for the maritime fleet cannot be compared.

Analysis of the distribution of injuries and injury costs in helicopter accidents indicates that a disproportionate share occur near the survivable limit in the referenced fleet of aircraft. Almost 40 percent of the injury costs occur within 15 ft/sec of the 95th-percentile survivable accident velocity. The design conditions contained in MIL-STD-1290(AV) and the U.S. Army Aircraft Crash Survival Design Guide are very similar to the 95th-percentile survivable accident conditions found for Navy and Marine helicopters in this study. With adaptation to the specific mission constraints, the MIL-STD-1290(AV) design conditions appear to be applicable to the design of future Navy and Marine helicopters. A similar analysis of injuries and injury costs was not conducted for the maritime aircraft due to the relatively few number of survivable accidents that could be examined. However, often the Navy's maritime aircraft have commercial counterparts. In studies of the commercial versions of these aircraft the Federal Aviation Administration (FAA) has determined that increased retention strength of seats (both crew and passenger) could reduce the incidence of serious injury. The FAA issued several Notices of Proposed Rulemaking (NPRM) in 1986 and 1987 to increase seat strength and require dynamic testing to verify performance under crash loading. The NPRM's cover both general avaition aircraft and transport-category aircraft. It is believed that the design and test requirements contained in the NPRM's are applicable to the Navy's maritime aircraft.

RECOMMENDATIONS

Studies such as this are valuable in assessing the state of crashworthiness in the current fleet of aircraft. Periodic evaluation of component performance is necessary to verify performance expectations. For example, performance of systems developed in current retrofit programs should be reviewed periodically to gather valuable field performance data.

The capability of studies such as this to evaluate specific hazards could be enhanced by improving the data base contained in the accident reports. There appear to be three possible approaches to improving and supplementing the information in the reports:

1. On-going advanced training of personnel involved in investigation, particularly in relation to survival aspects and accident reconstruction.

2. Development of additional accident report forms similar to forms employed by the U.S. Army and National Transportation Safety Board (NTSB) for evaluation of crash survival factors.

3. Equipping of a limited number of Navy and Marine helicopters and maritime aircraft with a crash recording system such as the Accident Information Retrieval System (AIRS) to gather accurate impact parameters in a sampling of accidents.

Another aspect that could enhance the usefulness of reports such as this would be to develop realistic cost assessments for injuries. Two areas warrant review:

1. Tabulation of actual costs for specific injuries, such as spinal compression fractures, that are typical to Navy flight mishaps.

2. Review of published cost data to ensure that it includes not only the immediate cost to the Navy (such as those contained in OPNAV Instruction P3750.6N), but also long-term costs such as litigation against the aircraft manufacturer, which eventually gets passed on in the form of higher procurement costs. These costs may be many times greater than the injury costs.

The number of major injuries and fatalities occurring in survivable accidents calls for review of specific aircraft components for possible retrofit improvements. Table 32 lists the helicopter series and recommended action. Table 33 lists the maritime aircraft series and recommended action.

The final recommendation is for the incorporation of crashworthiness into future Navy and Marine aircraft. The design levels specified in MIL-STD-1290(AV) are justified by the helicopter accident experience during the 1972 to 1981 evaluation period. Reduction below the MIL-STD-1290(AV) level is not warranted and certainly cannot be recommended based on the injury cost analysis, which indicates that a high percentage of costs occur in accidents near these impact conditions. For maritime aircraft, the injury costs may not warrant adaptation of a specification such as MIL-STD-1290(AV) to govern crashworthiness of the entire aircraft. However, use of crash-worthiness technology for specific components, such as seats and restraints, does appear to be justified. It is recommended that the recently proposed rules issued by he FAA (NPRM 86-11, 86-19, and 87-4) be used as guidelines for developing improved criteria for seat strength and dynamic testing.

Table 32. Potential Areas for Improvement in the Crashworthiness Capabilities of Existing Navy and Marine Helicopters (AH-1, H-1, H-2, H-3, H-46, AND H-53)

Area	Helicopter	Recommended Action
Crewseats	H-1 H-3 H-53	Retrofit seats with increased retention strength and vertical energy absorption capability
	H-46	Increase retention strength of pilot/copilot seats in helicopters prior to Bureau No. 155311* Monitor performance of CH-46E energy-absorbing seat
	AH-1 H-2	Evaluate minimum retention strength and upgrade
Troop Seats	H-1 H-53 H-46	Increase retention strength and add vertical energy absorption
Crash-Resistant Fuel Systems	H-53 H-1 H-3 AH-1	Retrofit improved bladders, fuel lines, and breakaway fittings
Restraint Systems	All Aircraft	Emphasize mandatory usage by all passengers
Gunner's Belt	H-46 H-53 H-1 H-3	Evaluate methods for providing improved crash restraint over existing gunner's belt, and provide retrofit kits
Flotation	H-46 H-3 H-2	Retrofit emergency flotation systems capable of sustaining ditching loads

*This modification was completed in CH-46 helicopters beginning with Bureau No. 155311.

Table 33. Potential Areas for Improvement in the Crashworthiness Capabilities of Existing Maritime Aircraft

Area	Aircraft	Recommended Action
Crewseats	Land Based Carrier Capable Trainers	Retrofit seats with increased retention strength and vertical energy absorption capability
Restraint Systems	All Aircraft	Emphasize mandatory usage by all passengers
Crash-Resistant Fuel Systems	Trainers	Retrofit to add (CRFS) bladders, fuel lines, and breakaway fittings

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APPENDIX A

INJURY COST DATA AND SUMMARY OF SPECIFIC INJURIES

Table A-1. Injury Cost Data for DOD Personnel
(Taken From Reference 4)

Injury Type	Submarine/ Flying Officer ($)	Other Officers ($)	Enlisted Personnel ($)	Civilian Employees ($)	Program Youth/Student Assistance Program Employees and Foreign Nationals ($)
Alfa Injury	330,000	150,000	47,000(1) 102,000(2)	174,000	102,000
Bravo Injury(3)	476,000	321,000	190,000	146,000	148,000
Charlie Injury(3)	80,000	55,000	43,000	96,000	67,000
Lost Workdays	170/day	170/day	120/day	100/day	75/day
Days Hospitalized(4)	445/day	445/day	395/day	375/day	350/day

(1) Non-aircrew

(2) Aircrew

(3) Total cost (includes lost workday and hospitalized day costs)

(4) Total costs (includes lost workday costs)

Table A-2. Summary of Injuries and Injury Severity Classification

Current Injury Classification According to OPNAV Instr. P3750.6N	Previous Classification (Used through 1976)	Approximate AIS* Severity Rating	Examples of Specific Injuries According to Severity Classification
Golf	None	0	Minimal or no injury
Foxtrot	Minor	1	Superficial contusions, lacerations, abrasions
Echo	Minor	1	Multiple superficial contusions, lacerations, abrasions Burns: 2^{o} or 3^{o}, less than 6% TBS** Rib fracture Lumbar, thoracic, or cervical spine strain
Delta	Major	2	Major contusions, lacerations, abrasions Burns: 2^{o} or 3^{o}, 6-15% TBS Cerebral concussion Inner or middle ear injury Simple mandible fracture Multiple rib fractures Minor spinal compression fracture Long bone fracture

*Abbreviated Injury Scale, AIS-80 (Reference 13).
**TBS = Total Body Surface.

Table A-2 (Contd). Summary of Injuries and Injury Severity Classifications

Current Injury Classification According to OPNAV Instr. P3750.6N	Previous Classification (Used through 1976)	Approximate AIS* Severity Rating	Examples of Specific Injuries According to Severity Classification
Charlie	Major	3 or 4	Burns: 2° or 3°, 16-25% TBS** Frontal skull fracture Hemothorax or pneumothorax Contusion of internal organs Major spinal compression fractures Crushing or amputation of extremity
Bravo	Major	4 or 5	Burns: 2° or 3°, 26-90% TBS Inhalation burn Epidural or subdural hematoma Basilar skull fracture Lumbar or thoracic spine fracture with nerve damage
Alpha	Fatal	6	Burns: 2° or 3°, greater than 91% TBS Crushed skull (ring fracture) Severance of the aorta Cervical spinal cord damage
Lima	Fatal	N/A	Lost at sea

*Abbreviated Injury Scale, AIS-80 (Reference 13).
**TBS = Total Body Surface.

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